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Transmitted herewith for filing is the patent application of:

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For: METHOD AND MESSAGE THEREFOR OF MONITORING THE SPARE CAPACITY OF A DRA NETWORK

Enclosed are: 47 Sheets of Informal Drawings

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METHOD AND MESSAGE THEREFOR OF MONITORING THE SPARE CAPACITY OF A DRA NETWORK

Cross Reference to Related Applications

This application is a continuation-in-part of patent application serial number 09/038,531 filed on March 11, 1998, which claims priority under 35 U.S.C. § 119(e) to provisional application number 60/040536, filed March 12, 1997. The instant invention relates to the following applications having serial No. 09/046,089 filed March 23, 1998, serial No. _____ (ALCA-1100-2) entitled "Restricted Reuse of Intact Portions of Failed Paths", serial No. _____ (ALCA-1100-7) entitled "Signal Conversion for Fault Isolation", and serial No. _____ (ALCA-1100-6) entitled "Method and Message Therefor of Monitoring The Spare Capacity of a DRA Network". The respective disclosures of those applications are incorporated by reference to the disclosure of the instant application.

Field of the Invention

This invention relates to a distributed restoration algorithm (DRA) network, and more particularly to a method of monitoring the topology of the spare links in the network for rerouting traffic in the event that the traffic is disrupted due to a failure in one of the working links of the network.

Background of the Invention

In a telecommunications network provisioned with a distributed restoration algorithm (DRA), the network is capable of restoring traffic that has been disrupted due to a fault or malfunction at a given location thereof. In such DRA provisioned network, or portions thereof which are known as domains, the nodes, or digital cross-connect switches, of the network are each equipped with the DRA algorithm and the associated hardware that allow each node to seek out an alternate route to reroute traffic that has been disrupted due to a malfunction or failure at one of the links or nodes of the network. Each of the nodes is interconnected, by means of spans that include working and spare links, to at least one other node. Thus, ordinarily each node is connected to an adjacent node by at least one working link and one spare link. It is by means of these links that messages, in addition to traffic signals, are transmitted to and received by the nodes.

In a DRA network, when a failure occurs at one of the working links, the traffic is rerouted by means of the spare links. Thus, to operate effectively, it is required that the spare links of the DRA network be functional at all times, or at the very least, the network has a preconceived notion of which spare links are functional and which are not.

There is therefore a need for the instant invention DRA network to always have an up-to-date map of the functional spare links, i.e. the spare capacity,

of the network, so that traffic that is disrupted due to a failure can be readily restored.

Summary of the Present Invention

To provide an up-to-date map of the functional spare links of the network, a topology of the network connected by the functional spare links is made available to the custodial nodes that bracket a malfunctioned link as soon as the failure is detected. The custodial node that is designated as the sender or origin node then uses the topology of the spare links to quickly reroute the traffic through the functional spare links.

To ensure that the spare links are functional, prior to the DRA process, special messages, referred to in this invention as keep alive messages, are continuously exchanged on the spare links between adjacent nodes. Each of these keep alive messages has a number of fields which allow it to identify the port of the node from which it is transmitted, the identification of the node, the incoming IP address and the outgoing IP address of the node, as well as a special field that identifies the keep alive message as coming from a custodial node when there is a detected failure. These keep alive message may be transmitted over the C-bit channels as idle signals.

So long as a spare link is operating properly, the keep alive messages that traverse therethrough will contain data that informs the network, possibly by way of the operation support system, of the various pairs of spare ports to which a spare link connects a pair of adjacent nodes. This information is collected by the

network and constantly updated so that at any moment, the network has a view of the entire topology of the network as to what spare links are available. This data can be stored in a database at the operation support system of the network, so that it may be provided to the origin node as soon as a failure is detected.

It is therefore an objective of the present invention to provide a method of mapping a topology of the spare capacity of a DRA network so that traffic may be routed through the functional spare links when a failure occurs at the network.

It is another objective of the present invention to provide a special message that is exchanged continuously between adjacent nodes before the occurrence of the failure in order to continually collect data relating to the available spare links of the network.

Brief Description of the Figures

The above mentioned objectives and advantages of the present invention will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 conceptually illustrates a simplified telecommunications restoration network to provide certain definitions applicable to the present invention;

FIGURE 2 illustrates a restoration subnetwork for illustrating concepts applicable to the present invention;

FIGURE 3 conceptually shows a failure within a restoration subnetwork;

FIGURE 4 illustrates two origins/destination nodes pairs for demonstrating the applicable scope of the present invention;

FIGUREs 5A and 5B illustrate the loose synchronization features of the present invention;

FIGURE 6 shows the failure notification message flow applicable to the present invention;

FIGURE 7 illustrates the flow of keep-alive messages according to the present invention;

FIGURE 8 illustrates the flow of path verification messages according to the teachings of the present invention;

FIGURE 9 shows a time diagram applicable to the failure notification and fault isolation process of the present invention;

FIGUREs 10 and 11 illustrate the AIS signal flow within the restoration subnetwork of the present invention;

FIGURE 12 describes more completely the failure notification message flow within the restoration subnetwork according to the present invention;

FIGURE 13 illustrates the beginning of an iteration of the restoration process of the present invention;

FIGURE 14 provides a timed diagram applicable to the explore, return, max flow and connect phases of the first iteration of the restoration process of the present invention;

FIGURE 15 provides a timed diagram associated with the explore phase of the process of the present invention;

FIGURE 16 illustrates the possible configuration of multiple origins/destination node pairs from a given origin node;

FIGURE 17 depicts two steps of the explore phase of the first iteration of the restoration process;

FIGURE 18 provides a timed diagram applicable to the return phase of the restoration process of the present invention;

FIGURE 19 shows steps associated with the return phase of the present process;

FIGUREs 20, 21 and 22 illustrates the link allocation according to the return phase of the present invention;

FIGURE 23 illustrates a typical return message for receipt by the origin node of a restoration subnetwork;

FIGURE 24 provides a timed diagram for depicting the modified map derived from the return messages received at the origin node;

FIGURE 26 shows the max flow output for the max flow phase of the present process;

FIGURE 27 illustrates an optimal routing applicable to the max flow output of the present invention;

FIGURE 28 provides a timed diagram for showing the sequence of the connect phase for the first iteration of the process of the present invention;

FIGURE 29 illustrates the connect messages for providing the alternate path routes between an origin node and destination node of a restoration subnetwork;

FIGUREs 30 and 31 show how the present invention deals with hybrid restoration subnetworks;

FIGUREs 32 and 33 illustrate the explore phase and return phase, respectively, applicable to hybrid networks;

FIGURE 34 shows the time diagram including an extra iteration for processing hybrid networks according to the teachings of the present invention;

FIGUREs 35 and 36 illustrate a lower quality spare according to the teachings of the present invention;

FIGURE 37 illustrate the use of a "I am custodial node" flag of the present invention;

FIGUREs 38 through 42 describe the restricted re-use features of the present invention;

FIGURE 43 describes the path inhibit feature of the present invention;

FIGURE 44 further describes the path inhibit feature of the present invention;

FIGURE 45 is an illustration of a telecommunications network of the instant invention;

FIGURE 46 is a block diagram illustrating two adjacent cross-connect switches and the physical interconnection therebetween; and

FIGURE 47 is an illustration of the structure of an exemplar keep alive message of the present invention.

Detailed Description of the Present Invention

FIGURE 1 shows telecommunications network portion 10, that includes node 12 that may communicate with node 14 and node 16, for example. Connecting between node 12 and 14 may be a set of links such as links 18 through 26, as well as for example, links 28 through 30 between node 12 and node 16. Node 14 and node 16 may also communicate between one another through links 32 through 36, for example, which collectively may be thought of as a span 38.

The following description uses certain terms to describe the concepts of the present invention. The term 1633SX is a cross-connect switch and is here called a "node." Between nodes are links, which may be a DS-3, and STS-1, which is essentially the same thing as a DS-3, but which conforms to a different standard. A link could be an STS-3, which is three STS-1s multiplexed together to form a single signal. A link may also be a STS-12, which is twelve STS-1s multiplexed together, or a link could be an STS-12C, which is twelve STS-12s, which are actually locked together to form one large channel. A link, however, actually is one unit of capacity for the purposes of the present invention. Thus, for purposes of the following description, a link is a unit of capacity connecting between one node and another. A span is to be understood as all of the links between two adjacent nodes. Adjacent nodes or neighbor nodes are connected by a bundle, which itself is made up of links.

For purposes of the present description, links may be classified as working, spare, fail, or recovered. A working link is a link that currently carries traffic. Spare links are operable links that are not currently being used. A spare link may be used whenever the network desires to use the link. A failed link is a link that was working, but has failed. A recovered link is a link that, as will be described more completely below, has been recovered.

FIGURE 2 illustrates the conceptual example of restoration subnetwork 40 that may include origin node 42 that through tandem nodes 44 and 46 connects to destination node 48. In restoration subnetwork 40, a path such as paths 50, 52, 54, and 56 includes connections to nodes 42 through 48, for example, as well as links between these nodes. As restoration subnetwork 40 depicts, each of the paths enters restoration subnetwork 40 from outside restoration subnetwork 40 at origin node 42.

With the present embodiment, each of nodes 42 through 48 includes an associated node identifier. Origin node 42 possesses a lower node identifier value, while destination node 48 possesses a higher node identifier value. In the restoration process of the present invention, the nodes compare node identification numbers.

The present invention establishes restoration subnetwork 40 that may be part of an entire telecommunications network 10. Within restoration

subnetwork 40, there may be numerous paths 50. A path 50 includes a number of links 18 strung together and crossconnected through the nodes 44. The path 50 does not start within restoration subnetwork 40, but may start at a customer premise or someplace else. In fact, a path 50 may originate outside a given telecommunications network 10. The point at which the path 50 enters the restoration subnetwork 40, however, is origin node 42. The point on origin node 42 at which path 50 comes into restoration subnetwork 40 is access/egress port 58.

In a restoration subnetwork, the failure may occur between two tandem nodes. The two tandem nodes on each side of the failure are designated as "custodial" nodes. If a single failure occurs in the network, there can be two custodial nodes. In the network, therefore, there can be many origin/destination nodes. There will be two origin nodes and two destination nodes. An origin node together with an associated destination node may be deemed an origin/destination pair. One failure may cause many origin/destination pairs.

FIGURE 3 illustrates the concept of custodial nodes applicable to the present invention. Referring again to restoration subnetwork 40, custodial nodes 62 and 64 are the tandem nodes positioned on each side of failed span 66. Custodial nodes 62 and 64 have bound the failed link

and communicate this failure, as will be described below. FIGURE 4 illustrates the aspect of the present invention for handling more than one origin-destination node pair in the event of a span failure. Referring to FIGURE 4, restoration subnetwork 40 may include, for example, origin node 42 that connects through custodial nodes 62 and 64 to destination node 48. Within the same restoration subnetwork, there may be more than one origin node, such as origin node 72. In fact, origin node 72 may connect through custodial node 62 and custodial node 64 to destination node 74. As in FIGURE 3, FIGURE 4 shows failure 66 that establishes custodial nodes 62 and 64.

The present invention has application for each origin/destination pair in a given restoration subnetwork. The following discussion, however, describes the operation of the present invention for one origin/destination pair. obtaining an understanding of how the present invention handles a single origin/destination pair makes clear how the algorithm may be extended in the event of several origin/destination pairs occurring at the same time. An important consideration for the present invention, however, is that a single cut may produce numerous origin/destination pairs.

FIGUREs 5A and 5B illustrate the concept of loose synchronization according to the present invention. "Loose synchronization" allows operation of the present

method and system as though all steps were synchronized according to a centralized clock. Known restoration algorithms suffer from race conditions during restoration that make operation of the restoration process unpredictable. The restoration configuration that results in a given network, because of race conditions, depends on which messages arrive first. The present invention eliminates race conditions and provides a reliable result for each given failure. This provides the ability to predict how the restored network will be configured, resulting in a much simpler restoration process.

Referring to FIGURE 5A, restoration subnetwork 40 includes origin node 42, that connects to tandem nodes 44 and 46. Data may flow from origin node 42 to tandem node 46, along data path 76, for example. Origin node 42 may connect to tandem node 44 via path 78. However, path 80 may directly connect origin node 42 with destination node 48. Path 82 connects between tandem node 44 and tandem node 46. Moreover, path 84 connects between tandem node 46 and destination node 48. As FIGURE 5A depicts, data may flow along path 76 from origin node 42 to tandem node 46, and from destination node 48 to origin node 42. Moreover, data may be communicated between tandem node 44 and tandem node 46. Destination node 48 may direct data to origin node 42 along data path 80, as well as to tandem node 46 using path 84.

These data flows will all take place in a single step. At the end of a step, each of the nodes in restoration subnetwork 40 sends a "step complete" message to its neighboring node. Continuing with the example of FIGURE 5A, in FIGURE 5B there are numerous step complete messages that occur within restoration subnetwork 40. In particular, step complete message exchanges occur between origin node 42 and tandem node 44 on data path 78, between origin node 42 and tandem node 46 on data path 76, and between origin node 42 and destination node 48 on data path 80. Moreover, tandem node 46 exchanges "step complete" messages with tandem node 44 on data path 82, and between tandem node 46 and destination node 48 on data path 84.

In the following discussion, the term "hop count" is part of the message that travels from one node to its neighbor. Each time a message flows from one node to its neighbor, a "hop" occurs. Therefore, the hop count determines how many hops the message has taken within the restoration subnetwork.

The restoration algorithm of the present invention may be partitioned into steps. Loose synchronization assures that in each step a node processes the message it receives from its neighbors in that step. Loose synchronization also makes the node send a step complete message to every neighbor. If a node has nothing to do in a given step, all it does is send a step complete message. When a node receives a step complete message from all of its neighbors, it

increments a step counter associated with the node and goes to the next step.

Once a node receives step complete messages from every neighbor, it goes to the next step in the restoration process. In looking at the messages that may go over a link, it is possible to see a number of messages going over the link. The last message, however, will be a step complete message. Thus, during the step, numerous data messages are exchanged between nodes. At the end of the step, all the nodes send step complete messages to their neighbors to indicate that all of the appropriate data messages have been sent and it is appropriate to go to the next step. As a result of the continual data, step complete, data, step complete, message traffic, a basic synchronization occurs.

In practice, although the operation is not as synchronized as it may appear in the associated FIGUREs, synchronization occurs. During the operation of the present invention, messages travel through the restoration subnetwork at different times. However, loose synchronization prevents data messages from flowing through the restoration subnetwork until all step complete messages have been received at the nodes. It is possible for one node to be at step 3, while another node is at step 4. In fact, at some 'places within the restoration subnetwork, there may be even further step differences between nodes. This helps

minimize the effects of slower nodes on the steps occurring within the restoration subnetwork.

The steps in the process of the present invention may be thought of most easily by considering them to be numbered. The process, therefore, starts at step 1 and proceeds to step 2. There are predetermined activities that occur at each step and each node possesses its own step counter. However, there is no master clock that controls the entire restoration subnetwork. In other words, the network restoration process of the present invention may be considered as a distributive restoration process. With this configuration, no node is any different from any other node. They all perform the same process independently, but in loose synchronization.

FIGURE 6 shows the typical form of a failure notification message through restoration subnetwork 40. If, for example, origin node 42 desires to start a restoration event, it first sends failure notification messages to tandem node 44 via data path 78, to tandem node 46 via data path 76, and destination node 48 via data path 80. As FIGURE 6 further shows, tandem node 44 sends failure notification message to tandem node 46 on path 82, as does destination node 48 to tandem node 46 on path, 84.

The process of the present invention, therefore, begins with a failure notification message. The failure notification message is broadcast throughout the restoration subnetwork to begin the restoration

process from one node to all other nodes. once a node receives a failure message, it sends the failure notification message to its neighboring node, which further sends the message to its neighboring nodes. Eventually the failure notification message reaches every node in the restoration subnetwork. Note that if there are multiple failures in a network, it is possible to have multiple failure notification messages flooding throughout the restoration subnetwork simultaneously.

The first failure notification message initiates the restoration algorithm of the present invention. Moreover, broadcasting the failure notification message is asynchronous in the sense that as soon as the node receives the failure notification message, it broadcasts the message to its neighbors without regard to any timing signals. It is the failure notification message that begins the loose synchronization process to begin the restoration process of the present invention at each node within the restoration subnetwork. Once a node begins the restoration process, a series of events occurs.

Note, however, that before the restoration process of the present invention occurs, numerous events are already occurring in the restoration subnetwork. One such event is the transmission and receipt of keep alive messages that neighboring nodes exchange between themselves.

FIGURE 7 illustrates the communication of keep-alive messages that the restoration process of the present invention communicates on spare links, for the purpose of identifying neighboring nodes. Referring to FIGURE 7, configuration 90 shows the connection via spare link 92 between node 94 and node 96. Suppose, for example, that node 94 has the numerical designation I'll", and port designation 11103". Suppose further that node 96 has the numerical designation 3 and the port designation 5. On spare link 92, node 94 sends keep-alive message 98 to node 96, identifying its node number "11" and port number "103". Also, from node 96, keep-alive message 100 flows to node 94, identifying the keep-alive message as coming from the node having the numerical value "3", and its port having the numerical value "5".

The present invention employs keep-alive signaling using C-Bit of the DS-3 formatted messages in restoration subnetwork 40, the available spare links carry DS-3 signals, wherein the C-bits convey special keep-alive messages. In particular, each keep-alive message contains the node identifier and port number that is sending the message, the WAN address of the node, and an "I am custodial node" indicator to be used for assessing spare quality.

An important aspect of the present invention relates to signaling channels which occurs when cross-connect nodes communicate with one another. There are two kinds of communications the cross-connects can

perform. One is called in-band, another is out-of-band. With in-band communication, a signal travels over the same physical piece of media as the working traffic. The communication travels over the same physical media as the path or the same physical media as the link. With out-of-band signals, there is freedom to deliver the signals between cross-connects in any way possible. Out-of-band signals generally require a much higher data rate.

In FIGURE 7, for example, in-band messages are piggybacked on links. out-of-band message traffic may flow along any other possible path between two nodes. With the present invention, certain messages must flow in-band. These include the keep-alive message, the path verification message, and the signal fail message. There are some signaling channels available to the restoration process of the present invention, depending on the type of link involved. This includes SONET links and asynchronous links, such as DS-3 links.

A distinguishing feature between SONET links and DS-3 links is that each employs a different framing standard for which unique and applicable equipment must conform. It is not physically possible to have the same port serve as a SONET port and as a DS-3 port at the same time. In SONET signal channeling, there is a feature called tandem path overhead, which is a signaling channel that is part of the signal that is multiplexed together. It is possible to separate this signal portion from the SONET signaling channel.

Because of the tandem path overhead, sometimes called the Z5 byte, there is the ability within the SONET channel to send messages.

On DS-3 links, there are two possible signaling channels. There is the C-bit and the X-bit. The C-bit channel cannot be used on working paths, but can only be used on spare or recovered links. This is because the DS-3 standard provides the option using the C-bit or not using the C-bit. If the C-bit format signal is used, then it is possible to use the C-bit for signaling. However, in this instance, working traffic does not use that format. Accordingly, the C-bit is not available for signaling on the working channels. It can be used only on spare links and on recovered links.

FIGURE 8 illustrates in restoration subnetwork 40 the flow of path verification messages from origin node 42 through tandem nodes 44 and 46 to destination node 48. Path verification message 102 flows from origin node 42 through tandem nodes 44 and 46 to destination node 48. In particular, suppose origin node 42 has the label 18, and that working path 52 enters port 58. Path verification message 102, therefore, contains the labels 18 and 53, and carries this information through tandem nodes 44 and 46 to destination node 48. Destination node 48 includes the label 15 and egress port 106 having the label 29. Path verification message 104 flows through tandem node 46 and 44 to origin node 42 for the purpose of identifying

destination node 48 as the destination node for working path 52.

A path verification message is embedded in a DS-3 signal using the X-bits which are normally used for very low speed single-bit alarm signaling. In the present invention, the X-bit state is overridden with short bursts of data to communicate signal identity to receptive equipment downstream. The bursts are of such short duration that other equipment relying upon traditional use of the X-bit for alarm signaling will not be disturbed.

The present invention also provides for confining path verification signals within a network. In a DRA-controlled network, path verification messages are imbedded in traffic-bearing signals entering the network and removed from signals leaving the network. Inside of the network, propagation of such signals is bounded based upon the DRA-enablement status of each port. The path verification messages identify the originating node and the destination node. The path verification messages occur on working links that are actually carrying traffic. The path verification message originates at origin node 42 and the restoration subnetwork and passes through tandem nodes until the traffic reaches destination node 48. Tandem nodes 44 and 46 between the origin node 42 and destination node 48, for example, can read the path verification message but they cannot modify it. At destination node 48, the path verification message is

stripped from the working traffic to prevent its being transmitted from the restoration subnetwork.

The present invention uses the X-bit to carry path verification message 104. one signal format that the present invention may use is the DS-3 signal format. While it is possible to easily provide a path verification message on SONET traffic, the DS-3 traffic standard does not readily permit using path verification message 104. The present invention overcomes this limitation by adding to the DS-3 signal, without interrupting the traffic on this signal and without causing alarms throughout the network, path verification message 104 on the DS-3 frame X-bit.

The DS-3 standard specifies that the signal is provided in frames. Each frame has a special bit in it called the X-bit. In fact, there are two X-bits, X-1 and X-2. The original purpose of the X-bit, however, was not to carry path verification message 104. The present invention provides in the X-bit the path verification message. This avoids alarms and equipment problems that would occur if path verification message 104 were placed elsewhere. An important aspect of using the X-bit for path-verification message 104 with the present embodiment relates to the format of the signal. The present embodiment sends path verification message 104 at a very low data rate, for example, on the order of five bits per second. By sending path verification message 104 on the X-bit very slowly, the possibility of causing an alarm in the network is

significantly reduced. Path verification message 104 is sent at a short burst, followed by a long waiting period, followed by a short burst, followed by a long waiting period, etc. This method of "sneaking" path verification message 104 past the alarms permits using path verification message 104 in the DS-3 architecture systems.

FIGURE 9 shows conceptually a timeline for the restoration process that the present invention performs. With time moving downward, time region 108 depicts the network status prior to a failure happening at point 110. At the point that a failure happens, the failure notification and fault isolation events occur in time span 112. Upon completion of this step, the first generation of the present process occurs, as indicated by space 114. This includes explore phase 116 having, for example three steps 118, 120 and 122. Return phase 124 occurs next and may include at least two steps 126 and 128. These steps are discussed more completely below.

Once a failure occurs, the process of the present invention includes failure notification and fault isolation phase 112. Failure notification starts the process by sending failure notification messages throughout the restoration subnetwork. Fault isolation entails determining which nodes are the custodial nodes. One reason that it is important to know the custodial nodes is that there are spares on the same span as the failed span. The present invention avoids

using those spares, because they are also highly likely to fail. Fault isolation, therefore, provides a way to identify which nodes are the custodial nodes and identifies the location of the fault along the path.

FIGURE 10 illustrates the flow of AIS signals 130 through restoration subnetwork 40. In the event of failure 66 between custodial nodes 62 and 64, the AIS message 130 travels through custodial node 62 to origin node 42 and out restoration subnetwork 40. Also, AIS message 130 travels through custodial node 64 and tandem node 46, to destination node 48 before leaving restoration subnetwork 40. This is the normal way of communicating AIS messages 130. Thus, normally every link on a failed path sees the same AIS signal.

FIGURE 11, on the other hand, illustrates the conversion of AIS signal 130 to "signal fail,, signals 132 and 134. SF message 132 goes to origin node 42, at which point it is reconverted to AIS message 132. Next, signal 134 passes through tandem node 46 en route to destination node 48,-which reconverts SF message 134 to AIS message 130.

FIGUREs 10 and 11, therefore, illustrate how the DS-3 standard specifies operations within the restoration subnetwork. For a DS-3 path including origin node 42 and destination node 48, with one or more tandem nodes 44, 46. Custodial nodes 62 and 64 are on each side of the link failure 66. AIS signal 130 is a DS-3 standard signal that indicates that there is an alarm downstream. Moreover, AIS signal 130 could

actually be several different signals. AIS signal 130 propagates downstream so that every node sees exactly the same signal.

With AIS signal 130, there is no way to determine which is a custodial node 62, 64 and which is the tandem node 44, 46. This is because the incoming signal looks the same to each receiving node. The present embodiment takes this into consideration by converting AIS signal 130 to a signal fail or SF signal 132. When tandem node 46 sees SF signal 134, it propagates it through until it reaches destination node 48 which converts SF signal 134 back to AIS signal 130.

Another signal that may propagate through the restoration subnetwork 40 is the ISF signal. The ISF signal is for a signal that comes into the restoration subnetwork and stands for incoming signal fail. An ISF signal occurs if a bad signal comes into the network. if it comes in as an AIS signal, there is the need to distinguish that, as well. In the SONET standard there is already an ISF signal. The present invention adds the SF signal, as previously mentioned. In the DS-3 standard, the SF signal already exists. The present invention adds the ISF signal to the DS-3 standard. Consequently, for operation of the present invention in the DS-3 standard environment, there is the addition of the ISF signal. For operation in the SONET standard environment, the present invention adds the SF signal. Therefore, for each of the standards, the present invention adds a new signal.

To distinguish whether an incoming non-traffic signal received by a node has been asserted due to an alarm within a DRA-controlled network, a modified DS-3 idle signal is propagated downstream in place of the usual Alarm Indication Signal (AIS). This alarm-produced idle signal differs from a normal idle signal by an embedded messaging in the C-bit maintenance channel to convey the presence of a failure within the realm of a particular network. The replacement of AIS with idle is done to aid fault isolation by squelching downstream alarms. Upon leaving the network, such signals may be converted back into AIS signals to maintain operational compatibility with equipments outside the network. A comparable technique is performed in a SONET network, where STS-N AIS signals are replaced with ISF signal and the ZS byte conveys the alarm information.

Another aspect of the present invention is the ability to manage unidirectional failures. In a distributed restoration environment, failures that occur along one direction of a bidirectional link are handled by first verifying that the alarm signal persists for a period of time and then propagating an idle signal back along the remaining working direction. This alarm produced idle signal differs from a normal idle signal by embedded messaging in the C-bit maintenance channel to convey the presence of a far end receive failure. In this manner, custodial nodes are promptly identified and restorative switching is

simplified by treating unidirectional failures as if they were bidirectional failures.

FIGURE 12 illustrates the broadcast of failure notification messages from custodial nodes 62 and 64. As FIGURE 12 depicts, custodial node 62 sends a failure notification to origin node 42, as well as to tandem node 136. Tandem node 136 further broadcasts the failure notification message to tandem nodes 138 and 140. In addition, custodial node 64 transmits a failure notification message to tandem node 46, which further transmits the failure notification message to destination node 48. Also, custodial node 64 broadcasts the failure notification message to tandem node 140.

FIGURE 13 illustrates the time diagram for the first iteration following fault isolation. In particular, FIGURE 13 shows the time diagram for explore phase 116 and return phase 124 of iteration 1. FIGURE 14 further illustrates the time diagram for the completion of iteration 1 and a portion of iteration 2. As FIGURE 14 indicates, iteration 1 includes explore phase 116, return phase 124, max flow phase 142 and connect phase 144. Max flow phase 142 includes a single step 146. Note that connect phase 144 of iteration 2 shown by region 148 includes six steps, 150 through 160, and occurs simultaneously with explore phase 162 of iteration 2. Note further that return phase 164 of iteration 2 also includes six steps 166 through 176.

Each iteration involves explore, return, maxflow, and connect phases. The restored traffic addressed by connect message and the remaining unrestored traffic conveyed by the explore message are disjoint sets. Hence, there is no conflict in concurrently propagating or combining these messaging steps in a synchronous DRA process. In conjunction with failure queuing, this practice leads to a restoration process that is both reliably coordinated and expeditious.

The iterations become longer in duration and include more steps in subsequent iterations. This is because with subsequent iterations, alternate paths are sought. A path has a certain length in terms of hops. A path may be three hops or four hops, for example. In the first iteration, for example, a hop count may be set at three. This, means that alternate paths that are less than or equal to three hops are sought. The next iteration may seek alternate paths that are less than or equal to six hops.

Setting a hop count limit per iteration increases the efficiency of the process of the present invention. With the system of the present invention, the number of iterations and the number of hop counts for each iteration is configurable. However, these may also be preset, depending on the degree of flexibility that a given implementation requires. Realize, however, that with increased configurability, increased complexity results. This increased complexity may, in some

instances, generate the possibility for inappropriate or problematic configurations.

FIGURE 15, for promoting the more detailed discussion of the explore phase, shows explore phase 116, which is the initial part of the first iteration 114. FIGURE 16 shows restoration network portion 170 to express the idea that a single origin node 42 may have more than one destination node. In particular, destination node 180 may be a destination node for origin node 42 through custodial nodes 62 and 66. Also, as before, destination node 48 is a destination node for origin node 42. This occurs because two working paths, 182 and 184, flow through restoration subnetwork portion 170, both beginning at origin node 42. During the explore phase, messages begin at the origin nodes and move outward through the restoration subnetwork. Each explore message is stored and forwarded in a loosely synchronized manner. Accordingly, if a node receives the message in step 1, it forwards it in step 2. The neighboring node that receives the explore message in step 1 transmits the explore message to its neighboring node in step 2. Because the present invention employs loose synchronization it does not matter how fast the message is transmitted from one neighbor to another, it will be sent at the next step irrespectively.

If the explore phase is three steps long, it may flood out three hops and no more. The following discussion pertains to a single origin-destination

pair, but there may be other origin/destination pairs performing the similar or identical functions at the same time within restoration subnetwork 40. If two nodes send the explore message to a neighboring node, only the first message received by the neighboring node is transmitted by the neighboring node. The message that is second received by the neighboring node is recognized, but not forwarded. Accordingly, the first node to reach a neighboring node with an explore message is generally the closest node to the neighboring node. When an explore message reaches the destination node, it stops. This step determines the amount of spare capacity existing in the restoration subnetwork between the origin node and the destination node.

Because of loose synchronization, the first message that reaches origin node 42 and destination node 48 will be the shortest path. There are no race conditions within the present invention's operation. In the explore message, the distance between the origin node and destination node is included. This distance, measured in hops, is always equal to or less than the number of steps allowed for the given explore phase. For example, if a destination node is five hops from the origin node by the shortest path, the explore phase with a three hop count limit will never generate a return message. On the other hand, an explore phase with a six hop count limit will return the five hop count information in the return message.

In the explore message there is an identification of the origin-destination pair to identify which node sent the explore message and the destination node that is to receive the explore message. There is also a request for capacity. The message may say, for example, that there is the need for thirteen DS-3s, because thirteen DS-3s failed. In practice, there may be not just DS-3s, but also STS-1s, STS-12C's, etc. The point being, however, that a certain amount of capacity is requested. At each node that the explore message passes through, the request for capacity is noted. The explore phase is over once the predetermined number of steps have been completed. Thus, for example, if the explore phase is to last three steps, at step 4, the explore phase is over. This provides a well-defined end for the explore phase.

FIGURE 17 illustrates restoration subnetwork 40 for a single-origin destination pair, including origin node 42 and destination node 48. In restoration subnetwork 40, origin node 42, at the beginning of the explore phase, takes step 1 to send an explore message to tandem node 44, tandem node 46 and tandem node 186. At step 2, tandem node 46 sends an explore message to tandem node 188 and to destination node 48. At step 2, tandem node 44 sends an explore message to tandem node 46, tandem node 46 sends an explore message to tandem node 188, and to destination node 48, and tandem node 186 sends explore messages to tandem node 46 and to destination node 48. Note that explore messages at

step 2 from tandem node 44 to tandem node 46 and from tandem node 186 to tandem node 46 are not forwarded by tandem node 46.

FIGURE 18 illustrates the time diagram for the next phase in the restoration process of the present invention, the return phase 24, which during the first iteration, includes three steps, 126, 128 and 129.

FIGURE 19 illustrates the return phase of the present invention, during the first iteration. Beginning at destination node 48, at step 4, return message flows on path 192 to tandem node 46, and on path 190 to tandem node 186. At step 5, the return message flows on path 76 to origin node 42. Also, from tandem node 186, a return message flows to origin node 42.

During the return phase, a return message flows over the same path traversed by its corresponding explore phase, but in the opposite direction. Messages come from the destination node and flow to the origin node. In addition, the return phase messages are loosely synchronized as previously described. The return phase messages contain information relating to the number of spare links available for connecting the origin node to the destination node.

In the return phase, information relating to the available capacity goes to the origin node. Beginning at destination node 48, and continuing through each tandem node 44, 46, 186 en route to origin node 42, the return message becomes increasingly longer. The return

message, therefore, contains information on how much capacity is available on each span en route to the origin node. The result of the return message received is the ability to establish at the origin node a map of the restoration network showing where the spare capacity is that is useable for the restoration.

FIGURE 20 illustrates tandem node 44, that connects to tandem node 46 through span 38. Note that span 38 includes six links 32, 34, 36, 196, 198 and 200. FIGUREs 21 and 22 illustrate the allocation of links between the tandem nodes 44, 46 according to the preferred embodiment of the present invention. Referring first to FIGURE 21, suppose that in a previous explore phase, span 38 between tandem nodes 44 and 46 carries the first explore message (5,3) declaring the need for four links for node 46, such as scenario 202 depicts. Scenario 204 shows further a message (11,2) requesting eight link flows from tandem node 44, port 2.

FIGURE 22 illustrates how the present embodiment allocates the six links of span 38. In particular, in response to the explore messages from scenarios 202 and 204 of FIGURE 21, each of tandem nodes 44 and 46 knows to allocate three links for each origin destination pair. Thus, between tandem nodes 44 and 46, three links, for example links 32, 34 and 36 are allocated to the (5,3) origin destination pair. Links 196, 198 and 200, for example, may be allocated to the origin/destination pair (11,2).

FIGURE 23 illustrates the results of the return phase of the present invention. Restoration subnetwork 40 includes origin node 42, tandem nodes 208, 210 and 212, as well as tandem node 44, for example. As FIGURE 23 depicts, return messages carry back with them a map of the route they followed and how much capacity they were allocated on each span. Origin node 42 collects all the return messages. Thus, in this example, between origin node 42 and tandem node 44, four links were allocated between origin node 42 and node 208. Tandem node 208 was allocated ten links to tandem node 210. Tandem node 210 is allocated three links, with tandem node 17. And tandem node 17 is allocated seven links with tandem node 44.

The next phase in the first iteration of the process of the present invention is the maxflow phase. The maxflow is a one-step phase and, as FIGURE 24 depicts, for example, is the seventh step of the first iteration. All of the work in the maxflow phase for the present embodiment occurs at origin node 42. At the start of the maxflow phase, each origin node has a model of part of the network. This is the part that has been allocated to the respective origin/destination pair by the tandem nodes.

FIGURE 25 illustrates that within origin node 42 is restoration subnetwork model 214, which shows what part of restoration subnetwork 40 has been allocated to the origin node 42-destination node 48 pair. In particular, model 214 shows that eight links have been

allocated between origin node 42 and tandem node 46, and that eleven links have been allocated between tandem node 46 and destination node 48. Model 214 further shows that a possible three links may be allocated between tandem node 46 and tandem node 186.

As FIGURE 26 depicts, therefore, in the maxflow phase 142 of the present embodiment, origin node 42 calculates alternate paths through restoration subnetwork 40. This is done using a maxflow algorithm. The maxflow output of FIGURE 26, therefore, is a flow matrix indicating the desired flow of traffic between origin node 42 and destination node 48. Note that the maxflow output uses neither tandem node 44 nor tandem node 188.

FIGURE 27 illustrates a breadth-first search that maxflow phase 142 uses to find routes through the maxflow phase output. In the example in FIGURE 27, the first route allocates two units, first from origin node 42, then to tandem node 186, then to tandem node 46, and finally to destination node 48. A second route allocates three units, first from origin node 42 to tandem node 186, and finally to destination node 48. A third route allocates eight units, first from origin node 42 to tandem node 46. From tandem node 46, these eight units go to destination node 48.

The last phase in the first iteration in the process of the present embodiment includes connect phase 144. For the example herein described, connect phase includes steps 8 through 13 of the first

iteration, here having reference numerals 150, 152, 154, 156, 220 and 222, respectively.

The connect phase is loosely synchronized, as previously described, such that each connect message moves one hop in one step. Connect phase 144 overlaps explore Phase 162 of each subsequent next iteration, except in the instance of the last iteration. Connect phase 144 distributes information about what connections need to be made from, for example, origin node 42 through tandem nodes 46 and 186, to reach destination node 48.

In connect phase 144, messages flow along the same routes as identified during maxflow phase 142. Thus, as FIGURE 29 suggests, a first message, M1, flows from origin node 42 through tandem node 186, through tandem node 46 and finally to destination node 48, indicating the connection for two units. Similarly, a second message, M2, flows from origin node 42 through tandem node 186 and then directly to destination node 48, for connecting a three-unit flow path. Finally, a third connect message, M3, emanates from origin node 42 through tandem node 46, and then the destination node 48 for allocating eight units. Connect phase 144 is synchronized so that each step in a message travels one hop.

For implementing the process of the present invention in an existing or operational network, numerous extensions are required. These extensions take into consideration the existence of hybrid

networks, wherein some nodes have both SONET and DS-3 connections. Moreover, the present invention provides different priorities for working paths and different qualities for spare links. Fault isolation presents a particular challenge in operating or existing environments, that the present invention addresses. Restricted reuse and spare links connected into paths are additional features that the present invention provides. Inhibit functions such as path-inhibit and node-inhibit are additional features to the present invention. The present invention also provides features that interface with existing restoration processes and systems, such as coordination with an existing restoration algorithm and process or similar system. To ensure the proper operation of the present invention, the present embodiment provides an exerciser function for exercising or simulating a restoration process, without making the actual connections for subnetwork restoration. Other features of the present implementation further include a drop-dead timer, and an emergency shutdown feature to control or limit restoration subnetwork malfunctions. Additionally, the present invention handles real life situations such as glass-throughs and staggered cuts that exist in communications networks. Still further features of the present embodiment include a hold-off trigger, as well as mechanisms for hop count and software revision checking, and a step timer to ensure proper operation.

FIGUREs 30 through 33 illustrate how the present embodiment addresses the hybrid networks. A hybrid network is a combination of asynchronous and SONET links. Restrictions in the way that the present invention handles hybrid networks include that all working paths must either be SONET paths with other than DS-3 loading, or DS-3 over asynchronous and SONET working paths with DS-3 access/egress ports. Otherwise, sending path verification messages within the restoration subnetwork 40, for example, may not be practical. Referring to FIGUREs 30 and 31, restoration subnetwork 40 may include SONET origin A/E port 42, that connects through SONET tandem port 44, through sonnet tandem port 46 and finally to sonnet destination A/E port 48. In FIGURE 31, origin A/E port 42 is a DS-3 port, with tandem port 44 being a sonnet node, and tandem port 46 being a DS-3 port, for example. Port 106 of destination node 48 is a DS-3 port. In a hybrid network, during the explore phase, origin node 42 requests different types of capacity. In the return phase, tandem nodes 44, 46 allocate different types of capacity.

An important aspect of connect phase 144 is properly communicating in the connect message the type of traffic that needs to be connected. This includes, as mentioned before, routing DS-3s, STS-1s, OC-3s, and OC-12Cs, for example. There is the need to keep track of all of the implementation details for the different types of traffic. For this purpose, the present

invention provides different priorities of working paths and different qualities of spare links. With the present embodiment of the invention, working traffic is prioritized between high priority and low priority working traffic.

SONET traffic includes other rules to address as well. For instance, a SONET path may include an OC-3 port, which is basically three STS-1 ports, with an STS-1 representing the SONET equivalent of a DS-3 port. Thus, an OC-3 node can carry the same traffic as can three STS-1. An OC-3 node can also carry the same traffic as three DS-3s or any combination of three STS-1 and DS-3 nodes. In addition, an OC-3 node may carry the same traffic as an STS-3. So, an OC-3 port can carry the same traffic as three DS-3, three STS-1, or one OC-3. Then, an OC-12 may carry an OC-12C. It may also carry the same traffic as up to four OC-3 ports, up to 12 STS-1 ports, or up to twelve DS-3 ports. With all of the possible combinations, it is important to make sure that the large capacity channels flow through the greatest capacity at first.

An important aspect of the present invention, therefore, is its ability to service hybrid networks. A hybrid network is a network that includes both SONET and asynchronous links, such as DS-3 links. The present invention provides restoration of restoration subnetwork 40 that may include both types of links. The SONET standard provides that SONET traffic is backward compatible to DS-3 traffic. Thus, a SONET

link may include a DS-3 signal inside it. A restoration subnetwork that includes both SONET and DS-3 can flow DS-3-signals, provided that both the origin A/E port 42 and the destination A/E port 48 are DS-3 ports. If this were not the case, there would be no way to send path verification messages 104 within restoration subnetwork 40.

As with pure networks, with hybrid networks, explore messages request capacity for network restoration. These messages specify what kind of capacity that is necessary. It is important to determine whether DS-3 capacity or SONET capacity is needed. Moreover, because there are different types of SONET links, there is the need to identify the different types of format of SONET that are needed. In the return phase, tandem nodes allocate capacity to origin-destination pairs. Accordingly, they must be aware of the type of spares that are available in the span. There are DS-3 spares and SONET spares. Capacity may be allocated knowing which type of spares are available. There is the need, therefore, in performing the explore and return phases, to add extensions that allow for different kinds of capacity. The explore message of the present invention, therefore, contains a request for capacity and decides how many DS-3s and how many SONET links are necessary. There could be the need for an STS-1, an STS-3C, or an STS-12C, for example. Moreover, in the return phase it is necessary to include in the return message the

information that there is more than one kind of capacity in the network. When traffic routes through the network it must be aware of these rules. For instance, a DS-3 failed working link can be carried by a SONET link, but not vice versa. In other words, a DS-3 cannot carry a SONET failed working path.

FIGUREs 32 and 33 illustrate this feature. For example, referring to FIGURE 32, origin node 42 may generate explore message to tandem node 44 requesting five DS-3s, three STS-1s, two STS-3(c)s, and one STS-12(c)s. As FIGURE 33 depicts, from the return phase, origin node 42 receives return message from tandem node 44, informing origin node 42 that it received five DS-3s, one STS-1, one STS-3(c), and no STS-12s.

For a hybrid restoration subnetwork 40, and in the maxflow phase, the present invention first routes OC-12C failed working capacity over OC-12 spare links. Then, the max flow phase routes OC-3C, failed working capacity, over OC-12 and OC-3 spare links. Next, the present embodiment routes STS-1 failed working links over OC-12, OC-3 and STS-1 spare links. Finally, the max flow phase routes DS-3 failed working links over OC-12, OC-3, STS-1, and DS-3 spare links. In the connect phase, the restoration subnetwork of the present invention responds to hybrid network in a manner so that tandem nodes get instructions to cross-connect more than one kind of traffic.

FIGURE 34 relates to the property of the present invention of assigning different priorities for working

paths, and different qualities for spare links. The present embodiment of the invention includes 32 levels of priority for working paths; priority configurations occur at origin node 42, for example. Moreover, the preferred embodiment provides four levels of quality for spare links, such as the following. A SONET 1 for N protected spare link on a span that has no failed links has the highest quality. The next highest quality is a SONET 1 for N protect port on a span that has no failed links. The next highest quality is a SONET 1 for N protected port on the span that has a failed link. The lowest quality is a SONET 1-for-N protect port on a span that has a failed link.

With this configuration, different priorities relate to working paths, and different qualities for spare links. At some stages of employing the present process, the feature of priority working paths and different quality spare links for some uses of the present process, it is possible to simplify the different levels of priority and different levels of quality into simply high and low. For example, high priority working links may be those having priorities 1 through 16, while low priority working links are those having priorities 17 through 32. High quality spares may be, for example, quality 1 spares, low quality spares may be those having qualities 2 through 4.

With the varying priority and quality assignments, the present invention may provide a method for restoring traffic through the restoration subnetwork.

For example, the present invention may first try to restore high priority failed working links on high-quality spare links, and do this as fast as possible. Next, restoring high-quality failed working links on low-quality spares may occur. Restoring low-priority failed working paths on low-quality spare links occurs next. Finally, restoring low priority failed working paths on high quality spare links.

To achieve this functionality, the present invention adds an extra iteration at the end of normal iterations. The extra iteration has the same number of steps as the iteration before it. Its function, however, is to address the priorities for working paths and qualities for spare links. Referring to FIGURE 34, during normal iterations, the present invention will restore high priority working paths over high-quality spare links. During the extra iteration, as the invention restores high-priority working paths over low-quality spare links, then low-priority working paths over low-quality spare links, and finally low-priority working paths over high-quality spare links. This involves running the max flow algorithm additional times.

The network restoration process of the present invention, including the explore, return, and connect messaging phases may be repeated more than once in response to a single failure episode with progressively greater hop count limits. The first set of iterations are confined in restoring only high priority traffic.

Subsequent or extra iterations may be used seek to restore whatever remains of lesser priority traffic. This approach give high priority traffic a preference in terms of path length.

FIGUREs 35-37 provide illustrations for describing in more detail how the present invention handles fault isolation. Referring to FIGURE 35, between tandem notes 44 and 46 appear spare link 92. Between custodial nodes 62 and 64 are working link 18 having failure 66 and spare link 196. If a spare link, such as spare link 196, is on a span, such as span 38 that has a failed working link, that spare link has a lower quality than does a spare link, such as spare link 92 on a span that has no failed links. In FIGURE 35, spare link 92 between tandem notes 46 and 48 is part of a span that includes no failed link. In this example, therefore, spare link 92 has a higher quality than does spare link 196.

Within each node, a particular order is prescribed for sorting lists of spare ports and lists of paths to restore. This accomplishes both consistent mapping and preferential assignment of highest priority to highest quality restoration paths. Specifically, spare ports are sorted first by type (i.e., bandwidth for STS-12, STS-3, then by quality and thirdly by port label numbers. Paths to be restored are sorted primarily by type and secondarily by an assigned priority value. This quality of a given restoration path is limited by the lowest quality link along the path.

In addition to these sorting orders, a process is performed upon these lists in multiple passes to assign traffic to spare ports while making best use of high capacity, high-quality resources. This includes, for example, stuffing high priority STS-1's onto any STS-12's that are left after all other STS-12 and STS-3 traffic has been assigned.

Rules determine the proper way of handling different priorities of working paths and different qualities of spares in performing the restoration process. In our embodiment of the invention, there may be, for example, 32 priority levels. The working traffic priority may depend on business-related issues, such as who is the customer, how much money did the customer pay for communications service, what is the nature of the traffic. Higher priority working channels are more expensive than are lower priority channels. For example, working are assigned priorities according to these types of considerations. Pre-determined configuration information of this type may be stored in the origin node of the restoration subnetwork. Thus, for every path in the origin node priority information is stored. Although functionally there is no difference between a high priority working path and lower priority working path, though higher priority working paths will have their traffic restored first and lower priority working paths will be restored later.

The present embodiment includes four qualities of spare links. Spare link quality has to do with two factors. A link may either be protected or nonprotected by other protection schemes. In light of the priorities of failed working paths and the quality of spare links, the present invention uses certain rules. The first rule is to attempt to restore the higher priority failed working paths on the highest quality spare links. The next rule is to restore high quality failed working paths on both high quality and low quality spares. The third rule is to restore low priority failed working paths on low quality spares. The last thing to do is to restore low priority working paths over high and low quality spares.

The present invention also it possible for a node to know when it is a custodial node. Because there are no keep-alive messages on working links, however, the custodial node does not know on what span the failed link resides. Thus, referring to FIGURE 36, custodial node 64 knows that custodial node 62 is on the other end of spare link 196. The difficulty arises, however, in the ability for custodial nodes 62 and 64 to know that working link 18 having failure 66 and spare link 196 are on the same span, because neither custodial node 62 nor custodial node 64 knows on what span is working link 18.

FIGURE 37 illustrates how the present embodiment overcomes this limitation. Custodial node 64, for example, sends a "I am custodial node,, flag in the

keep alive messages that it sends on spare links, such as to non-custodial tandem node 46. Also, custodial node 64 and custodial node 62 both send "I am custodial node" flags on spare 196, to each other. In the event that the receiving non-custodial node, such as tandem node 46, is not itself a custodial node, then it may ignore the "I am custodial node", flag. Otherwise, the receiving node determines that the failure is on the link between itself and the custodial node from which the receiving custodial node receives the "I am custodial node" flag.

There may be some limitations associated with this procedure, such as it may be fooled by "glass throughs" or spans that have no spares. However, the worst thing that could happen is that alternate path traffic may be placed on a span that has a failed link, i.e., a lower quality spare.

The present embodiment provides this functionality by the use of an "I am custodial node" flag that "piggybacks" the keep alive message. Recalling that a custodial node is a node on either side of a failed link, when the custodial node is identified, the "I am custodial node" flag is set. If the flag appears on a spare link, that means that the neighboring link is the custodial node. This means that the node is adjacent to a failure. If the node receiving the flag is also a custodial node, then the spare is on the span that contains the failed link. So, the custodial node that is sending the flag to the non-custodial node, but not

getting it back from a non-custodial node a flag, this means that the spare link is not in a failed span.

FIGUREs 38-42 illustrate the restricted re-use feature of the present invention. The present invention also includes a restricted re-use function. A recovered link relates to the feature of restricted re-use. Given a path with a failure in it, a recovered link may exist between two nodes. The recovered link is a good link but is on a path that has failed. FIGURE 38 shows restoration subnetwork 40 that includes origin node 42 on link 18 and through custodial nodes 62 and 64 connects to destination node 48. Failure 66 exists between custodial nodes 62 and 64. The restricted re-use feature of the present invention involves what occurs with recovered links, such as recovered link 224.

With the present invention, there are at least three possible modes of re-use. One mode of re-use is simply no re-use. This prevents the use of recovered links to carry alternate path traffic. Another possible re-use mode is unrestricted re-use, which permits recovery links to carry alternate path traffic in any possible way. Still another re-use mode, and one that the present embodiment provides, is restricted re-use. Restricted re-use permits use of recovered links to carry alternate path traffic, but only the traffic they carry before the failure.

FIGURE 39 illustrates the restricted re-use concept that the present invention employs. Link 18

enters origin node 42 and continues through tandem node 226 on link 228 and 230 through custodial node 64 through recovered link 48.

Restricted re-use includes modifications to the explore and return phases of the present invention wherein the process determines where recovered links are in the network. The process finds the recovered links and sends this information to the origin node. The origin node collects information about where the recovered links are in the network to develop a map of the recovered links in the restoration subnetwork. The tandem nodes send information directly to the origin node via the wide are network about where the re-use links are.

FIGURE 40 through 42 illustrate how the present embodiment achieves restricted re-use. Referring to restoration subnetwork portion 40 in FIGURE 40, origin node 42 connects through tandem node 44 via link 78, to tandem node 46 via link 82, to tandem node 186 via link 84, and to destination node 48 via link 190. Note that between tandem node 46 and tandem node 186 appears failures 66.

To implement restricted re-use in the present embodiment, during the explore and return phases the origin node 42 will acquire a map of recovered links. Thus, as FIGURE 40 shows within origin node 42, recovered links 232, 234, and 236 are stored in origin node 42. This map is created by sending in-band messages, re-use messages, during the explore phase,

along recovered links from the custodial nodes to the origin and destination nodes, such as origin node 42 and destination node 48. Thus, as FIGURE 41 illustrates, in the explore phase, reuse messages emanate from tandem node 46 to tandem node 44 and from there to origin node 42. From tandem node 186, the re-use message goes to destination node 48.

In the return phase, such as FIGURE 42 depicts, the destination node sends the information that it has acquired through re-use messages to the origin node by piggybacking it on return messages. Thus, as shown in FIGURE 42, designation node 48 sends on link 192 a return plus re-use message to tandem node 46. In response, tandem node 46 sends a return plus re-use message on link 76 to origin node 42.

With the restricted re-use feature and in the max flow phase, origin node 42 knows about recovered links and "pure" spare links. When the origin node runs the max flow algorithm, the recovered links are thrown in with the pure spare links. When the breadth-first-search is performed, the present invention does not mix recovered links from different failed working paths on the same alternate path.

Another feature of the present invention relates to spare links connected into paths. In the event of spare links being connected into paths, often these paths may have idle signals on them or a test signal. If a spare link has a test signal on it, it is not possible to distinguish it from a working path. In

this instance, the present invention avoids using spare links with "working" signals on them

In the max flow phase, the origin has discovered what may be thought of as pure spare link. The origin node also receives information about recovered links, which the present invention limits to restricted re-use. In running the max flow algorithm during the max flow phase of the present process, the pure spare and recovered links and used to generate a restoration map of the restoration subnetwork, first irrespective of whether the links are pure, spare or recovered.

Another aspect of the present invention is the path inhibit function. FIGUREs 43 and 44 illustrate the path inhibit features of the present invention. For a variety of reasons, it may be desirable to temporarily disable network restoration protection for a single port on a given node. It may be desirable, later, to turn restoration protection back on again without turning off the entire node. All that is desired, is to turn off one port and then be able to turn it back on again. This may be desirable when maintenance to a particular port is desired. When such maintenance occurs, it is desirable not to have the restoration process of the present invention automatically initiate. The present invention provides a way to turn off subnetwork restoration on a particular port. Thus, as FIGURE 43 shows, origin node 42 includes path 2 to tandem node 44. Note that no link appears between node 42 and 44. This signifies

that the restoration process of the present invention is inhibited along path 240 along origin node 42 and tandem node 44. Working path 242, on the other hand, exist between origin node 42 and tandem node 46. Link 76 indicates that the restoration process of the present invention is noninhibited along this path if it is subsequently restored.

During the path inhibit function, the process of the present invention inhibits restoration on a path by blocking the restoration process at the beginning of the explore phase. The origin node either does not send out an explore message at all or sends out an explore message that does not request capacity to restore the inhibited path. This is an instruction that goes to the origin node. Thus, during path inhibit, the process of the present invention is to inform origin node 42, for example, to inhibit restoration on a path by sending it a message via the associated wide area network.

Referring to FIGURE 44, therefore, tandem node 46 sends a path inhibit message to origin node 42. Tandem node 46 receives, for example, a TL1 command telling it to temporarily inhibit the restoration process on a port. It sends a message to origin node 42 for that path via wide area network as arrow 246 depicts.

Tandem node 46 sends inhibit path message 246 with knowledge of the Internet protocol address of its source node because it is part of the path verification message. There may be some protocol involved in

performing this function. This purpose would be to cover the situation wherein one node fails while the path is inhibited.

Another feature of the present invention is that it permits the inhibiting of a node. With the node inhibit function, it is possible to temporarily inhibit the restoration process of the present invention on a given node. This may be done, for example, by a TL1 command. A node continues to send its step-complete messages in this condition. Moreover, the exerciser function operates with the node in this condition.

To support the traditional field engineering use of node port test access and path loopback capabilities, the restoration process must be locally disabled so that any test signals and alarm conditions may be asserted without triggering restoration processing. According to this technique as applied to a given path, a port that is commanded into a test access, loopback, or DRA-disabled mode shall notify the origin node of the path to suppress DRA protection along the path. Additional provisions include automatic timeout of the disabled mode and automatic loopback detection/restoration algorithm suppression when a port receives an in-band signal bearing its own local node ID.

Direct node-node communications are accomplished through a dedicated Wide Area Network. This approach bypasses the use of existing in-band and out-of-band call processing signaling and network control links for

a significant advantage in speed and simplicity. In addition, the WAN approach offers robustness by diversity.

A triggering mechanism for distributed restoration process applies a validation timer to each of a collection of alarm inputs, keeps a count of the number of validated alarms at any point in time, and generates a trigger output whenever the count exceeds a preset threshold value. This approach reduces false or premature DRA triggering and gives automatic protect switching a chance to restore individual link failures. It also allows for localizing tuning of trigger sensitivity based on quantity and coincidence of multiple alarms.

The preferred embodiment provides a step Completion Timer in Synchronous DRA. For each DRA process initiated within a network node, logic is provided for automatically terminating the local DRA process whenever step completion messages are not received within a certain period of time as monitored by a failsafe timer. Other causes for ending the process are loss of keep alive signals through an Inter-node WAN link, normal completion of final DRA iteration, consumption of all available spare ports, or an operation support system override command.

Another aspect of the present invention is a method for Handling Staggered Failure Events in DRA. In a protected subnetwork, an initial link failure, or a set of nearly simultaneous failures, trigger a

sequence of DRA processing phases involving message flow through the network. Other cuts that occur during messaging may similarly start restoration processing and create confusion and unmanageable contentions for spare resources. The present technique offers an improvement over known methods. In particular, during explore and return messaging phases, any subsequent cuts that occur are "queued" until the next Explore phase. Furthermore, in a multiple iteration approach, Explore messaging for new cuts is withheld while a final Explore/Return/Connect iteration occurs in response to a previous cut. These late-breaking held over cuts effectively result in a new, separate invocation of the DPA process.

The present invention includes failure notification messages that include information about the software revision and hop count table contents that are presumed to be equivalent among all nodes. Any nodes that receive such messages and find that the local software revision or hop count table contents disagree with those of the incoming failure notification message shall render themselves ineligible to perform further DRA processing. However, a node that notices a mismatch and disable DPA locally will still continue to propagate subsequent failure notification messages.

The present invention provides a way to Audit restoration process data within nodes that include asserting and verifying the contents of data tables

within all of the nodes in a restoration-protected network. In particular, such data may contain provisioned values such as node id, WAN addresses, hop count sequence table, and defect threshold. The method includes having the operations support system disable the restoration process nodes, write and verify provisionable data contents at each node, then re-enabling the restoration process when all nodes have correct data tables.

In a data transport network that uses a distributed restoration approach, a failure simulation can be executed within the network without disrupting normal traffic. This process includes an initial broadcast of a description of the failure scenario, modified DRA messages that indicate they are "exercise only" messages, and logic within the nodes that allows the exercise to be aborted if a real failure event occurs during the simulation.

Another aspect of the present invention is the ability to coordinate with other restoration processes such as, for example, the RTR restoration system. With the present invention, this becomes a challenge because the port that is protected by the restoration process of the present invention is often also protected by other network restoration algorithms.

Another aspect of the present invention is the exerciser function. The exerciser function for the restoration process of the present invention has two purposes. one is a sanity check to make sure that the

restoration process is operating properly. The other is an exercise for capacity planning to determine what the restoration process would do in the event of a link failure. With the present invention, the exerciser function operates the same software as does the restoration process during subnetwork restoration, but with one exception. During the exerciser function, connections are not made. Thus, when it comes time to make a connection, the connection is just not made.

With the exerciser function, essentially the same reports occur as would occur in the event of a link failure. Unfortunately, because of restrictions to inband signaling, there are some messages that may not be exchanged during exercise that would be exchanged during a real event. For that reason, during the exercise function it is necessary to provide the information that is in these untransmittable messages. However, this permits the desired exerciser function.

Another aspect of the present invention is a dropdead timer and emergency shut down. The drop-dead timer and emergency shut down protect against bugs or defects in the software. If the restoration process of the present invention malfunctions due to a software problem, and the instructions become bound and aloof, it is necessary to free the restoration subnetwork. The dropdead timer and emergency shut down provide these features. The drop-dead timer is actuated in the event that a certain maximum allowed amount of time in the restoration process occurs. By establishing a

maximum operational time the restoration network can operate for 30 seconds, for example, but no more. If the 30 second point occurs, the restoration process turns off.

An emergency shut down is similar to a drop-dead timer, but is manually initiated. For example, with the present invention, it is possible to enter a TL1 command to shut down the restoration process. The emergency shut down feature, therefore, provides another degree of protection to compliment the drop dead timer.

Out-of-band signaling permits messages to be delivered over any communication channel that is available. For this purpose, the present invention uses a restoration process wide area network. For purposes of the present invention, several messages get sent out of band. These include the explore message, the return message, the connect message, the step complete message, as well as a message known as the exercise message which has to do with an exerciser feature of the present invention. The wide area network of the present invention operates under the TCP/IP protocol, but other protocols and other wide area networks may be employed. In order to use the wide area network in practicing the present invention, there is the need for us to obtain access to the network. For the present invention, access to the wide area network is through two local area network Ethernet ports. The two Ethernet ports permit communication

with the wide area network. In the present embodiment of the invention, the Ethernet is half duplex, in the sense that the restoration subnetwork sends data in one direction on one Ethernet while information flows to the restoration subnetwork in the other direction on the other Ethernet port. The wide area network of the present invention includes a backbone which provides the high bandwidth portion of the wide area network. The backbone includes the same network that the restoration subnetwork protects. Thus, the failure in the restoration subnetwork could potentially cut the wide area network. This may make it more fragile.

Accordingly, there may be more attractive wide area networks to use with the present invention. For example, it may be possible to use spare capacity as the wide area network. In other words, there may be spare capacity in the network which could be used to build the wide area network itself. This may provide the necessary signal flows to the above-mentioned types of messages. With the present invention, making connections through the wide area network is done automatically.

For the cross-connects of the present invention, there is a control system that includes a number of computers within the cross-connect switch. The crossconnect may include possibly hundreds of computers. These computers connect in the hierarchy in three levels in the present embodiment. The computers that perform processor-intensive operations appear at

the bottom layer or layer 3. Another layer of computers may control, for example, a shelf of cards. These computers occupy layer 2. The layer 1 computers control the layer 2 computers.

The computers at layer 1 perform the instructions of the restoration process of the present invention. This computer may be centralized in the specific shelf where all layer 1 computers are in one place together with the computer executing the restoration process instructions. Because the computer performing the restoration process of the present invention is a layer 1 computer, it is not possible for the computer itself to send in-band messages. If there is the desire to send an in-band message, that message is sent via a layer 3 computer. This is because the layer 3 computer controls the local card that includes the cable to which it connects. Accordingly, in-band messages are generally sent and received by layer 2 and/or layer 3 computers, and are not sent by layer 1 computers, such as the one operating the restoration instructions for the process of the present invention.

Fault isolation also occurs at layer 2 and layer 3 computers within the cross-connects. This is because fault isolation involves changing the signals in the optical fibers. This must be done by machines at lower layers. Moreover, a port, which could be a DS-3 port or a SONET port, has a state in the lower layer processors keep track of the port state. In essence, therefore, there is a division of labor between layer 2

and 3 computers and the layer 1 computer performing the instructions for the restoration process of the present invention.

The exemplar telecommunications network of the instant invention, as shown in FIGURE 45, comprises a number of nodes 302-324 each connected to adjacent nodes by at least one working link and one spare link. For example, node 302 is connected to node 304 by means of a working link 2-4W and a spare link 2-4S. Similarly, node 304 is connect to node 306 by a working link 4-6W and a spare link 4-6S. For the sake of simplicity, only the specific links connecting nodes 302-304, 304-306 and 302-310 are appropriately numbered in FIGURE 45. But it should be noted that the working and spare links connecting adjacent nodes can be similarly designated.

For the telecommunications network of FIGURE 45, it is assumed that all of the nodes of the network are provisioned with a distributed restoration algorithm (DRA), even though in practice oftentimes only one or more portions of the telecommunications network are provisioned for distributed restoration. In those instances, those portions of the network are referenced as dynamic transmission network restoration (DTNR) domains.

Also shown in FIGURE 45 is an operation support system (OSS) 326. OSS 326 is where the network management monitors the overall operation of the network. In other words, it is at OSS 326 that an

overall view, or map, of the layout of each node within the network is provided. OSS 326 has a central processor 328 and a memory 330 into which data retrieved from the various nodes are stored. Memory 330 may include both a working memory and a database store. An interface unit, not shown, is also provided in OSS 326 for interfacing with the various nodes. As shown in FIGURE 45, for the sake of simplicity, only nodes 302, 304, 306, and 308 are shown to be connected to OSS 326. Given the interconnections between OSS 326 and the nodes of the network, the goings on within each of the nodes of the network is monitored by OSS 326.

Each of nodes 302-324 of the network comprises a digital cross-connect switch such as the 1633-SX broadband cross-connect switch made by the Alcatel Network System company. Two of such adjacently connected switches are shown in FIGURE 46. The FIGURE 46 switches may represent any two adjacent switches shown in the FIGURE 45 network such as for example nodes 304 and 306 thereof. As shown, each of the switches has a number of access/egress ports 332, 334 that are shown to be multiplexed to a line terminating equipment (LTE) 336, 338. LTEs 336 and 338 are SONET equipment having a detector residing therein for detecting any failure of the links between the various digital cross-connect switches. Again, for the sake of simplicity, such LTE is not shown to be sandwiched between nodes 334 and 336, as detection circuits for interpreting whether a communication failure has

occurred may also be incorporated within the respective working cards 340a, 340b of node 304 and 342a and 342b of node 306.

As shown in FIGURE 46, each of the digital cross-connect switches has two working links 344a and 344b communicatively connecting node 304 and node 306, by means of the respective working interface cards 340a, 340b and 342a, 342b. Also shown connecting node 304 and node 306 are a pair of spare links 346a and 346b, which are connected to the spare link interface cards 348a, 348b and 350a, 350b of node 304 and node 306, respectively. For the FIGURE 46 embodiment, assume that each of working links 344a, 344b and spare links 346a, 346b is a part of a logical span 352. Further note that even though only four links are shown to connect node 304 to node 306, in actuality, adjacent nodes may be connected by more or less links. Likewise, even though only four links are shown to be a part of span 352, in actuality, a span that connects two adjacent nodes may in fact have a greater number of links. For the instant discussion, assume that working links 344a and 344b correspond to the working link 4-6W of FIGURE 45 while the spare links 346a and 346b of FIGURE 46 correspond to the spare link 4-6S of FIGURE 45. For the purpose of the instant invention, each of the links shown in FIGURE 46 is presumed to be a conventional optical carrier OC-12 fiber or is a link embedded within a higher order (i.e., OC-48 or OC-192) fiber.

Focusing onto node 304 for the time being, note that each of the interfacing card, or boards, of that digital cross-connect switch such as 340a, 340b, 348a and 348b are connected to a number of STS-1 ports 352 for transmission to SONET LTE 336. Although not shown, an intelligence such as a processor residing in each of the digital cross-connect switches controls the routing and operation of the various interfacing boards and ports. Also not shown but present in each of the digital cross-connect switches is a database storage for storing a map which identifies the various sender nodes, chooser nodes and addresses, which will be discussed later. The working boards 342a, 342b and the spare boards 350a, 350b are likewise connected to the access/egress ports 354 in node 306. Further shown in FIGURE 46 are non-DRA between adjacent nodes 304 and 306.

For the instant invention, the access/egress ports such as 332 and 334 send their respective port numbers through the matrix in each of the digital cross-connects to its adjacent nodes. Thus, for the exemplar interconnected adjacent nodes 304 and 306, ports 352a and 352b of node 304 are connected to ports 354a and 354c of node 6 by means of working link 344a. Similarly, ports 352e and 352f are interconnected to ports 354e and 354f of node 306 by way of spare links 346a and 346b, respectively. Thus, if node 304 were to transmit a signal using spare link 346a to node 306, it will be transmitting such a message from its port 352e

to spare card 348a, and then onto spare link 346a, so that the message is received at spare card 350a of a conventional optical carrier OC-12 fiber or is a link embedded within a higher order (i.e., OC-48 or OC-192) fiber.

Focusing onto node 304 for the time being, note that each of the interfacing card, or boards, of that digital cross-connect switch such as 340a, 340b, 348a and 348b are connected to a number of STS-1 ports 352 for transmission to SONET LTE 336. Although not shown, an intelligence such as a processor residing in each of the digital cross-connect switches controls the routing and operation of the various interfacing boards and ports. Also not shown but present in each of the digital cross-connect switches is a database storage for storing a map which identifies the various sender nodes, chooser nodes and addresses, which will be discussed later. The working boards 342a, 342b and the spare boards 350a, 350b are likewise connected to the access/egress ports 354 in node 306. Further shown in FIGURE 46 are non-DRA between adjacent nodes 304 and 306.

For the instant invention, the access/egress ports such as 332 and 334 send their respective port numbers through the matrix in each of the digital cross-connects to its adjacent nodes. Thus, for the exemplar interconnected adjacent nodes 304 and 306, ports 352a and 352b of node 304 are connected to ports 354a and 354c of node 306 by means of working link 344a.

Similarly, ports 352e and 352f are interconnected to ports 354e and 354f of node 306 by way of spare links 346a and 346b, respectively. Thus, if node 304 were to transmit a signal using spare link 346a to node 306, it will be transmitting such a message from its port 352e to spare card 348a, and then onto spare link 346a, so that the message is received at spare card 350a of node 306 and then routed to the receiving port 354e of node 306. Thus, as long as each of the working links and spare links interconnecting a pair of adjacent nodes, such as for example nodes 304 and 306 are operational, when a message is sent between those nodes, the information relating to the respective transmit and receiving ports can be collected by the OSS 326 (FIGURE 45) so that a record can be collected of the various ports that interconnect any two adjacent nodes.

For the instant invention, the inventors have seized upon the idea that a topology, or map, of the available spare capacity of the network, in the form of the available spare links that interconnect the nodes, can be generated from stored data that is representative of the different port numbers of the various nodes to which spare links are connected. In other words, if a message transmitted by one node to its adjacent node is able to provide OSS 326 a number of parameters which include for example the ID of the transmit node, the respective IP (internal protocol) addresses of the transmit and receiving ports of the

node and the port number from which the message is transmitted from the node, the OSS can ascertain, from similar messages that are being exchanged between adjacent nodes on spare links connecting those adjacent nodes, an overall picture of the spare capacity of the network.

Simply put, if each of the digital cross-connect switches in the DRA provisioned network knows what port number and the node that it is connected to by its spare link, then that node knows how to reroute traffic if it detects a failure in one of its working links. And by collecting the information relating to each of the nodes of the network, the OSS 326 is able to obtain an overall view of all of the available spare links that interconnect the various nodes. As a consequence, when a failure occurs at a given working link, OSS 326 can send to the custodial nodes of the failed link a map of the spare capacity of the network, so that whichever custodial node designated as the sender or origin node can then use that map of the spare capacity of the network to begin the restoration process by finding an alternate route for rerouting the disrupted traffic.

The structure of the special message to be used for continuously monitoring the available spare capacity of the network is shown in FIGURE 47. For the instant invention, this message is referred to as a "keep alive" message. As shown, this keep alive message has a number of fields. Field 356 has an 8 bit

message field. For the FIGURE 47 message, the 8 bits of data can be configured to represent the keep alive message so that each node in receipt of the message will recognize that it is a keep alive message for updating the availability status of the spare link from which the message is received. OSS 326, on the other hand, upon receipt of a keep alive message, would group it with all the other keep alive messages received from the different nodes for mapping the spare capacity of the network.

The next field of the message of FIGURE 47 is field 358, which is an 8 bit field that contains the software revision number of the DRA being used in the network. The next field is 360, which is an 8 bit field containing the node identifier of the transmitting node. Field 362 is a 16 bit field that contains the port number of the transmitting node from which the keep alive message is sent.

The next field of the message is field 364. This is a 32 bit field that contains the IP address of the DS3 port on the node that is used for half duplex incoming messages. The IP address of the DS3 port of the node that is used for half-duplex outgoing messages is contained in the 32 bit field 66.

Field 368 is a 1 bit field that, when set, indicates to the receiving node that the message is sent from a custodial node for a failure. In other words, when there is a failure, the custodial node of the failed link will send out a keep alive message that

informs nodes downstream thereof that the keep alive message is being sent from a custodial node since a failure has occurred, and a restoration process will proceed.

The last field of the keep alive message is field 370. It has 7 bits and is reserved for future usage.

In operation, before any failure is detected, keep alive messages such as that shown in FIGURE 47 are exchanged on the spare links between adjacent nodes continuously. By the exchange of these keep alive messages, the network is able to keep a tab of the various available and functional spare links and also identify the port number of each node from where each spare link outputs a keep alive message, as well as the port number of the adjacent node to which the spare link is connected and to which the keep alive message is received. By collecting the data that is contained in each of the keep alive messages, a record is kept of the various nodes, the port numbers, the incoming and outgoing IP addresses of the various spare links that are available in the network. And from these collected data, a topology of the available spare capacity of the network can be generated, by either the OSS 326, or by each of the nodes, which can have the collected information downloaded thereto for storage. In any event, a map of the available spare links of the network is available, so that when a failure does occur, the custodial nodes of the failure could retrieve the up-to-date map of the spare capacity of

the network, and based on that, be able to find the most efficient alternate route for rerouting the disrupted traffic.

Given that the instant invention relates to a distributed restoration process, it should be noted that an OSS is not necessary for storing the topology of the spare capacity of the network, as each of the digital cross-connect switches of the network knows what port number and the nodes that it is connected to by its spare links. Thus, when a failure occurs, each of the nodes will continue to send the keep alive message, as the origin node that is responsible for restoration can built the entire topology of the available spare links by retrieving the different keep alive messages from the various nodes. Putting it differently, an origin node, in attempting to determine the available spare links, only needs to take the sum of all of the keep alive messages since each node that has at least one spare link will send a keep alive message to the origin node. And, by retrieving the ID of the node and the port numbers of the node to which spare links are connected, the spare capacity of the network can be ascertained. As a consequence, the map of the spare link topology becomes available in a distributed matter to the origin node in the instant invention DRA provisioned network.

Inasmuch as the present invention is subject to many variations, modifications and changes in detail, it is intended that all matter described throughout

this specification and shown in the accompanying drawings be interpreted as illustrative only and not in a limiting sense. Accordingly, it is intended that the present invention be limited only by the spirit and scope of the hereto appended claims.

Claims

1. A method of mapping a topology of the spare capacity of a distributed restoration algorithm (DRA) provisioned telecommunications network having a plurality of nodes interconnected with working and spare links, comprising the steps of:

a) outputting a message from each spare link of each of said nodes to the adjacent node to which said each spare link is connected;

b) identifying the port number of said each node from where said each spare link outputs said message and the port number of the adjacent node connected to said each spare link whereat said message is received;

c) storing as data the respective port numbers of all nodes that have connected thereto at least one spare link via which said message is either sent or received, the identifies of said all nodes and the spare links interconnecting said all nodes; and

d) generating from said stored data the topology of all spare links interconnecting the nodes of said network.

2. The method of claim 1, further comprising the steps of;

storing said data in a central processing means; and

providing said generated topology of the spare links of said network to the origin node for

beginning the restoration process if a failure occurs in said network.

3. The method of claim 1, wherein when a failure occurs in said network, further comprising the step of:

transmitting from each of the custodial nodes of the failed link a message, via any functional spare links that it has, to nodes downstream thereof to inform said downstream nodes that it is a custodial node.

4. The method of claim 1, further comprising the steps of:

selecting one of the custodial nodes of a failed link to be the origin node; and

said origin node utilizing said topology of the spare capacity of said network to find an alternate route to reroute the disrupted traffic.

5. The method of claim 2, further comprising the steps of:

continuously updating the status of said message arriving at each spare port of the nodes of said network; and

storing said updated status in said central processing means;

wherein said central processing means is adaptable to use said updated status to provide a real time topology of the spare capacity of said network.

6. In a distributed restoration algorithm (DRA) provisioned telecommunications network having a plurality of nodes interconnected with working and spare links, a method of continuously monitoring the available spare capacity of said network, comprising the steps of:

a) generating keep alive messages;

b) continuously exchanging said keep alive messages on the spare links of said network when a DRA event is not in progress; and

c) recording the various spare ports that transmitted and received said keep alive messages to determine the number of spare links available in said network.

7. The method of claim 6, wherein said step c further comprises the step of:

generating each of said keep alive messages to include

a first field containing the identification number of the node that sent said message;

a second field containing the identification number of the port of said node whence said message is output;

a third field having an identifier that is set to a specific value when said node is one of the custodial nodes that bracket a failed link.

8. The method of claim 7, further comprising the step of:

generating each of said keep alive messages to include a fourth field identifying said keep alive message to be a message that is continuously transmitted and exchanged along spare links between adjacent nodes of said network while a DRA process is not in progress.

9. In a distributed restoration algorithm (DRA) provisioned telecommunications network having a plurality of nodes interconnected with working and spare links, a message being transmitted between adjacent nodes of said network that are connected by at least one spare link for mapping the topology of the spare capacity of said network, comprising:

a first field containing the identification number of the node that sent said message;

a second field containing the identification number of the port of said node whence said message is output; and

a third field having an identifier that is set to a specific value when said node is one of the custodial nodes that bracket a failed link;

wherein, when there is a failed link, said message is broadcast from one of the custodial nodes that bracket said failed link.

10. The message of claim 9, wherein said message further comprises:

a fourth field for identifying said message to be a message that is continuously transmitted and exchanged along spare links between adjacent nodes of said network while a DRA process is not in progress.

Abstract of the Disclosure

To obtain a topology of the available spare links in a telecommunications network provisioned with a distributed restoration algorithm, messages containing the appropriate identifications of the nodes and the ports of the nodes to which spare links are connected are exchanged continuously along the spare links of the network. When a failure is detected, the origin node can retrieve the various messages, and from data contained therein, to construct a topology of the available spare links of the network which can then be used for finding an alternate route for rerouting the traffic disrupted by the failure.

FIG. 1

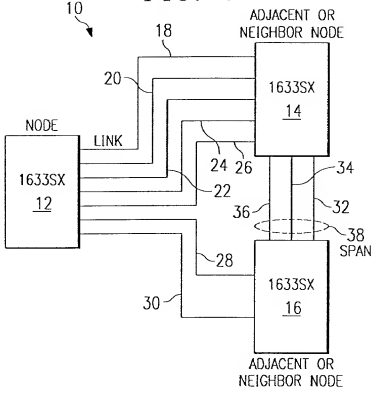

10
18
ADJACENT OR
NEIGHBOR NODE
20
1633SX
14
NODE
LINK
24
26
34
1633SX
12
22
36
32
38
SPAN
28
1633SX
16
30
ADJACENT OR
NEIGHBOR NODE

FIG. 2

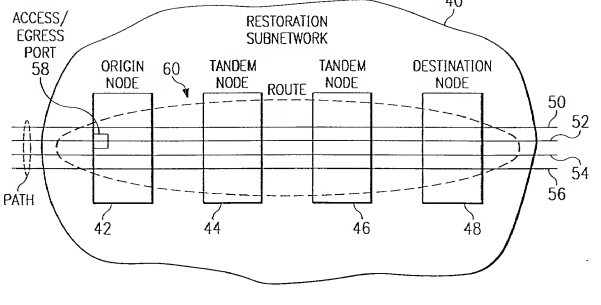

40
ACCESS/
EGRESS
PORT
58
RESTORATION
SUBNETWORK
ORIGIN
NODE
60
TANDEM
NODE
ROUTE
TANDEM
NODE
DESTINATION
NODE
50
52
54
56
PATH
42
44
46
48

FIG. 3

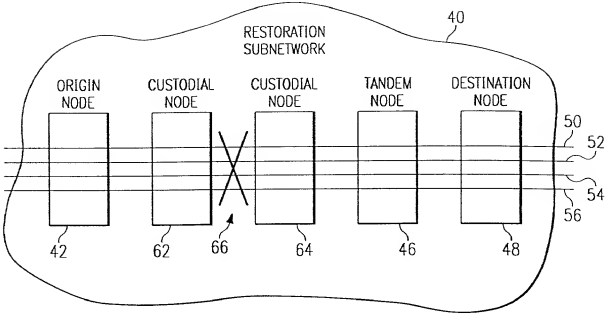
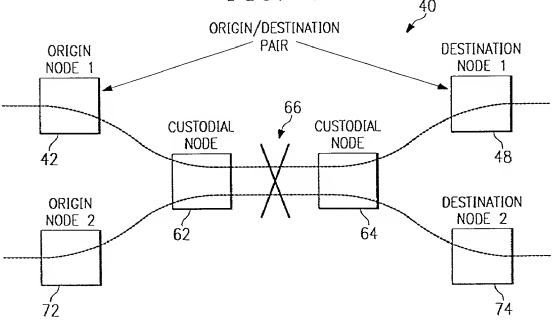

40
RESTORATION SUBNETWORK
ORIGIN NODE
CUSTODIAL NODE
CUSTODIAL NODE
TANDEM NODE
DESTINATION NODE
50
52
54
56
42
62
66
64
46
48

FIG. 4


40
ORIGIN/DESTINATION PAIR
ORIGIN NODE 1
DESTINATION NODE 1
66
CUSTODIAL NODE
CUSTODIAL NODE
42
48
ORIGIN NODE 2
DESTINATION NODE 2
62
64
72
74

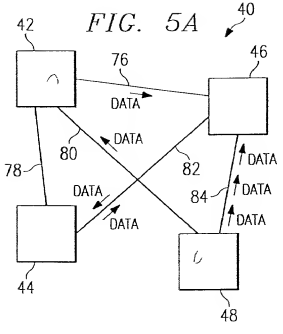


FIG. 5A

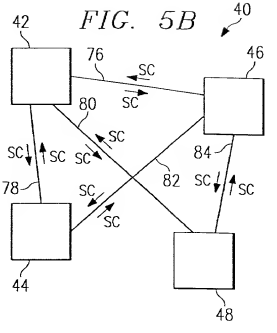


FIG. 5B

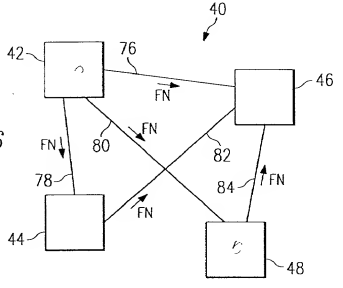


FIG. 6

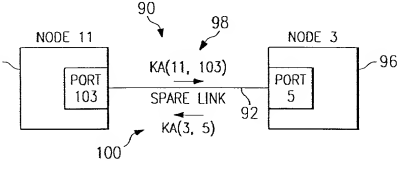


FIG. 7

FIG. 8

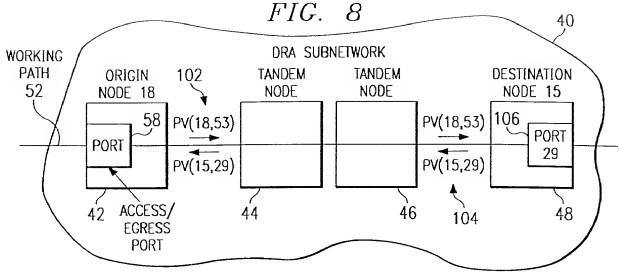


FIG. 9

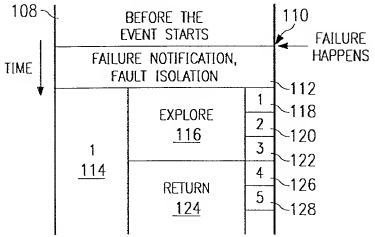
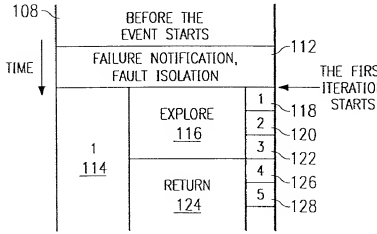


FIG. 13



40
52
AIS
ORIGIN NODE
42
AIS
CUSTODIAL NODE
62
AIS
130
66
AIS
130
CUSTODIAL NODE
64
AIS
TANDEM NODE
46
AIS
DESTINATION NODE
48

FIG. 10

40
52
AIS
130
ORIGIN NODE
42
SF
132
CUSTODIAL NODE
62
AIS
130
66
AIS
130
CUSTODIAL NODE
64
SF
134
TANDEM NODE
46
SF
134
DESTINATION NODE
48
AIS
130

FIG. 11

40
138
FN
136
FN
CUSTODIAL NODE
62
FN
42
66
140
FN
CUSTODIAL NODE
64
FN
46
FN
48

FIG. 12

ITERATION
PHASE
STEP
118
120
122
126
128
146
150
152
154
156
158
160
166
168
170
172
174
176
1
114
2
148
EXPLORE 116
RETURN 124
MAXFLOW 142
EXPLORE 162
CONNECT 144
RETURN 164
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
TIME

FIG. 14

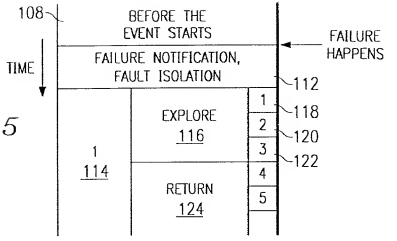


FIG. 15

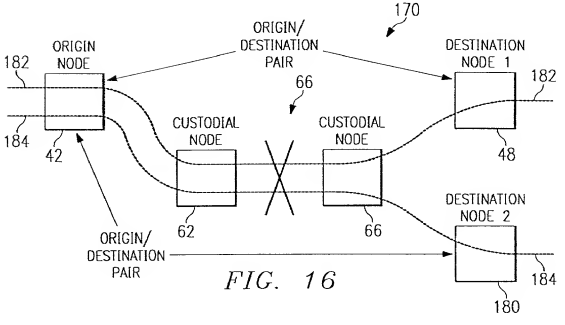


FIG. 16

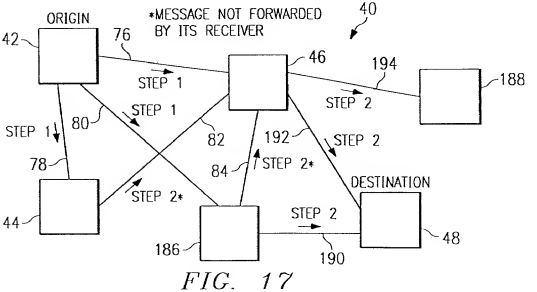


FIG. 17

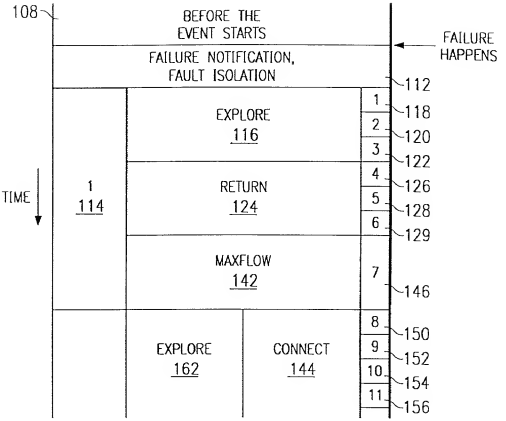

108
BEFORE THE EVENT STARTS
FAILURE NOTIFICATION, FAULT ISOLATION
FAILURE HAPPENS
112
TIME
1
114
EXPLORE
116
RETURN
124
MAXFLOW
142
EXPLORE
162
CONNECT
144
1
2
3
4
5
6
7
8
9
10
11
118
120
122
126
128
129
146
150
152
154
156

FIG. 18

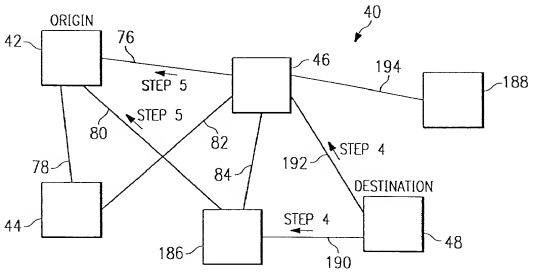

ORIGIN
42
76
40
46
194
188
STEP 5
STEP 5
80
82
78
84
192
STEP 4
DESTINATION
44
STEP 4
186
190
48

FIG. 19

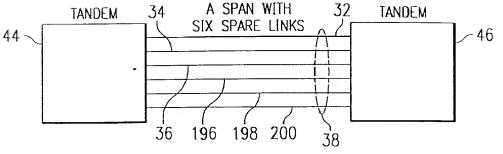

TANDEM
34
A SPAN WITH
SIX SPARE LINKS
32
TANDEM
44
46
36
196
198
200
38

FIG. 20

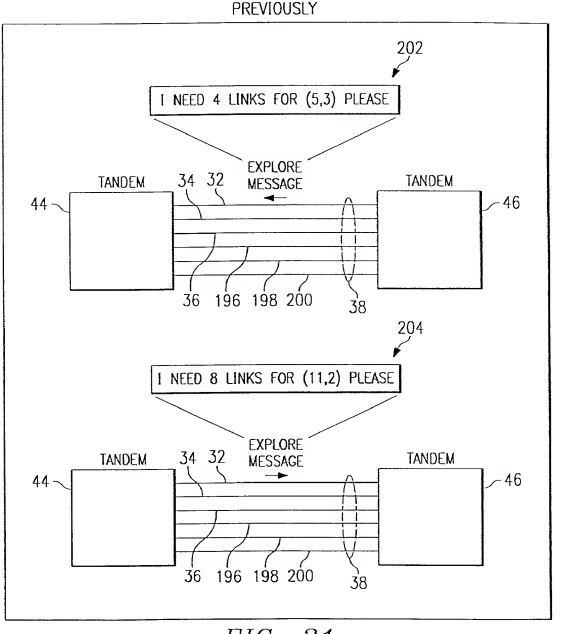

PREVIOUSLY
202
I NEED 4 LINKS FOR (5,3) PLEASE
EXPLORE
MESSAGE
TANDEM
34
32
TANDEM
44
46
36
196
198
200
38
204
I NEED 8 LINKS FOR (11,2) PLEASE
EXPLORE
MESSAGE
TANDEM
34
32
TANDEM
44
46
36
196
198
200
38

FIG. 21

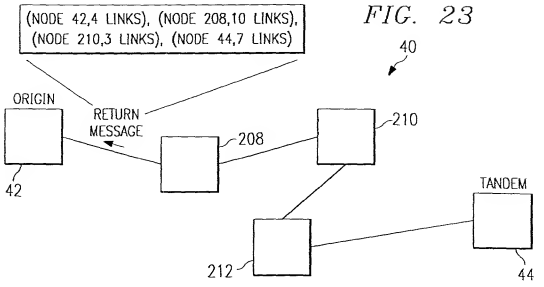

(NODE 42,4 LINKS), (NODE 208,10 LINKS),
(NODE 210,3 LINKS), (NODE 44,7 LINKS)
40
ORIGIN
RETURN
MESSAGE
208
210
42
TANDEM
212
44

FIG. 23

FIG. 24

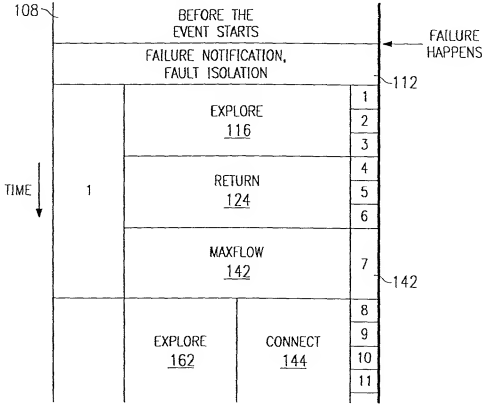

108
BEFORE THE
EVENT STARTS
FAILURE
HAPPENS
FAILURE NOTIFICATION,
FAULT ISOLATION
112
EXPLORE
116
RETURN
124
MAXFLOW
142
142
TIME
1
EXPLORE
162
CONNECT
144
1
2
3
4
5
6
7
8
9
10
11

FIG. 22

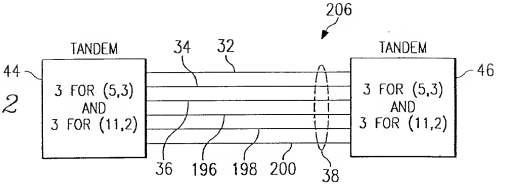


FIG. 25

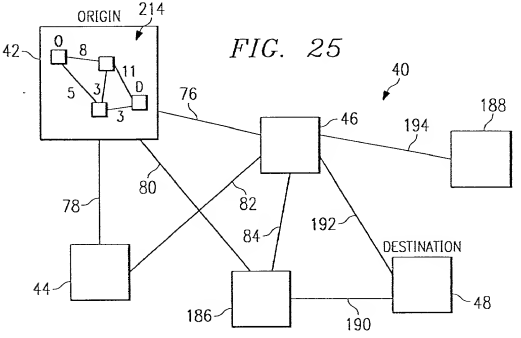
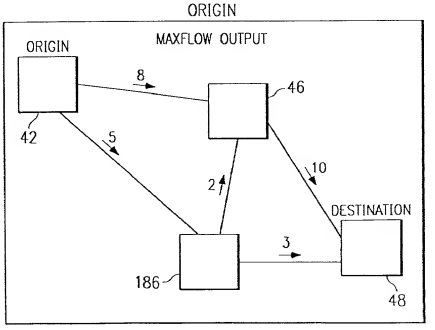


FIG. 26



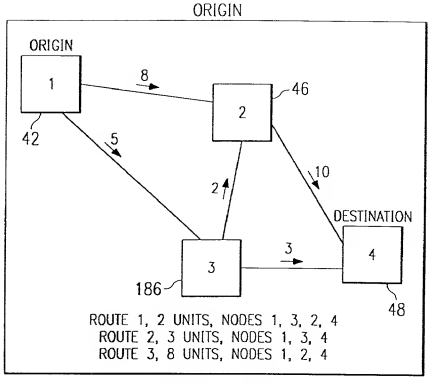

ORIGIN
ORIGIN
1
8
2
46
42
5
2
10
DESTINATION
3
4
3
186
48
ROUTE 1, 2 UNITS, NODES 1, 3, 2, 4
ROUTE 2, 3 UNITS, NODES 1, 3, 4
ROUTE 3, 8 UNITS, NODES 1, 2, 4

FIG. 27

FIG. 28

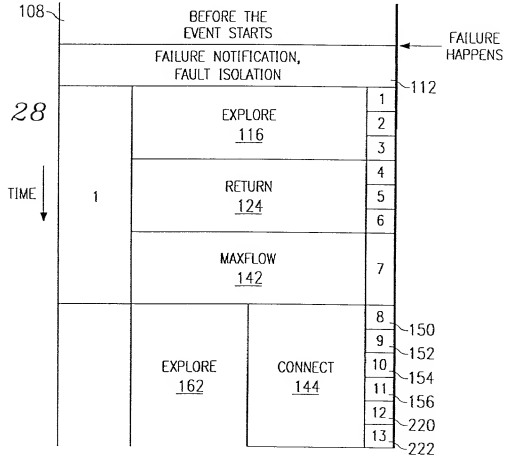

108
BEFORE THE EVENT STARTS
FAILURE HAPPENS
FAILURE NOTIFICATION, FAULT ISOLATION
112
TIME
1
EXPLORE 116
RETURN 124
MAXFLOW 142
EXPLORE 162
CONNECT 144
1
2
3
4
5
6
7
8
9
10
11
12
13
150
152
154
156
220
222

FIG. 29

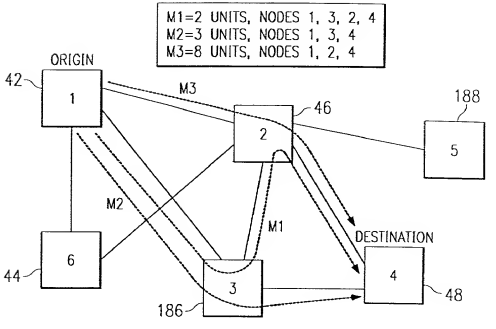


FIG. 30

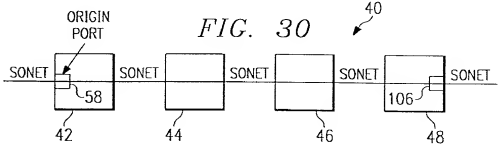


FIG. 31

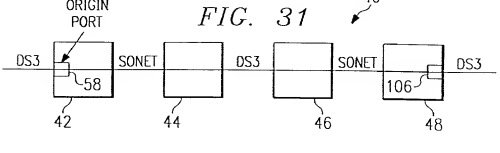


FIG. 32

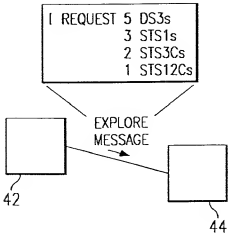


FIG. 33

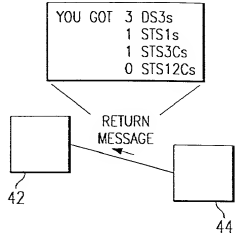


FIG. 34

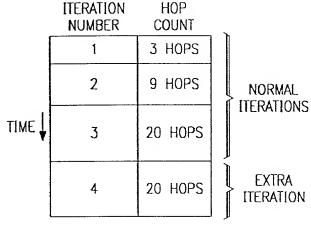


FIG. 35

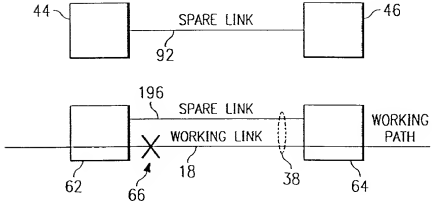


FIG. 36

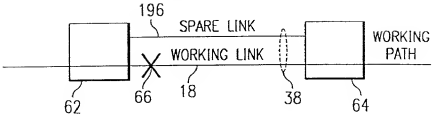


FIG. 37

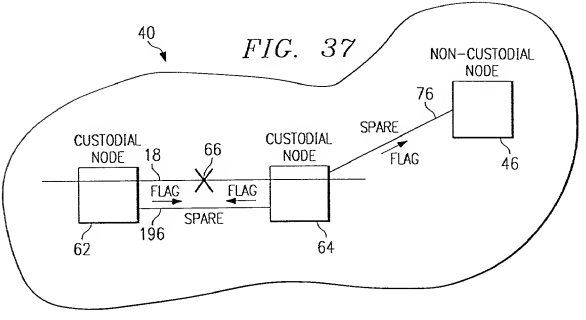


FIG. 38

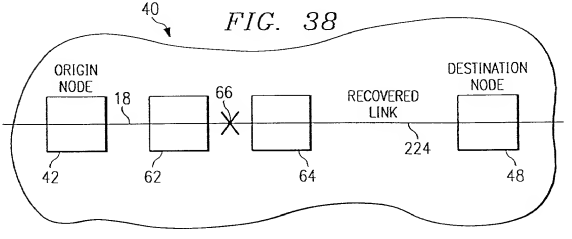


FIG. 39

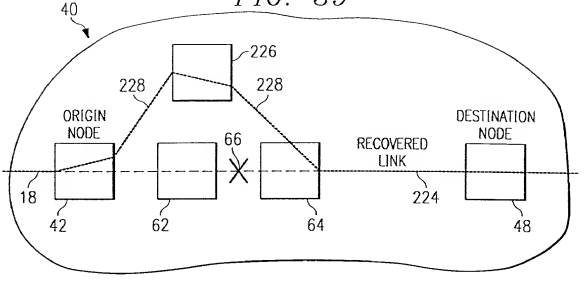
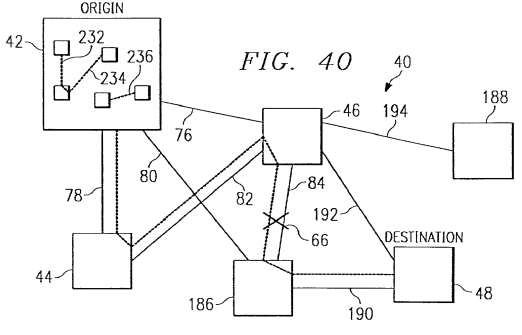

40
226
228
228
ORIGIN NODE
66
RECOVERED LINK
DESTINATION NODE
18
42
62
64
224
48

FIG. 40


ORIGIN
42
232
236
234
40
46
194
188
76
80
78
82
84
192
66
DESTINATION
44
186
190
48

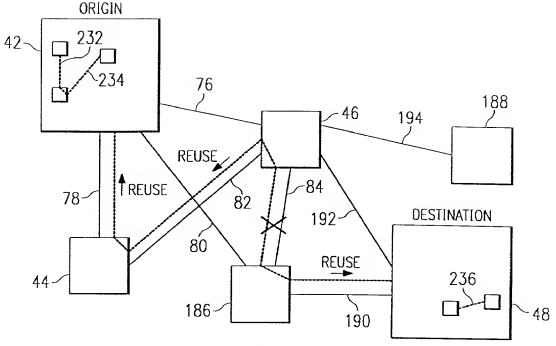

ORIGIN
42
232
234
76
46
194
188
REUSE
78
REUSE
82
84
192
DESTINATION
80
REUSE
44
236
186
190
48

FIG. 41

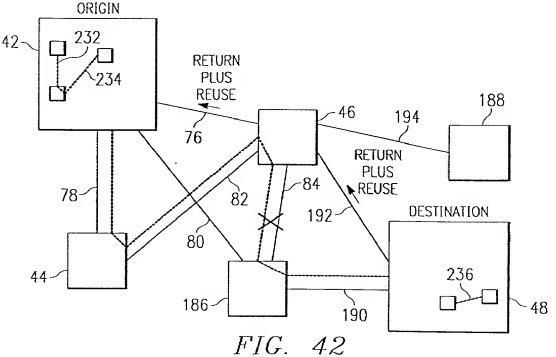

ORIGIN
42
232
234
RETURN
PLUS
REUSE
76
46
194
188
RETURN
PLUS
REUSE
78
82
84
192
DESTINATION
80
44
236
186
190
48

FIG. 42

FIG. 43

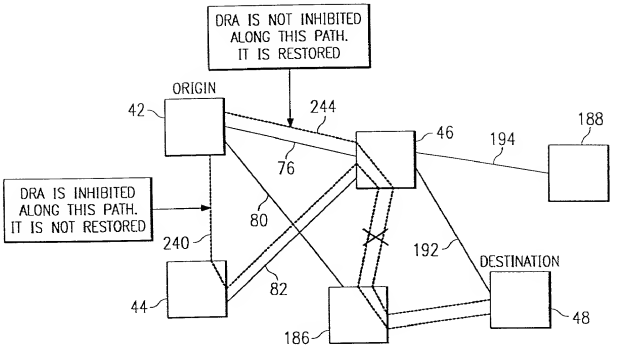
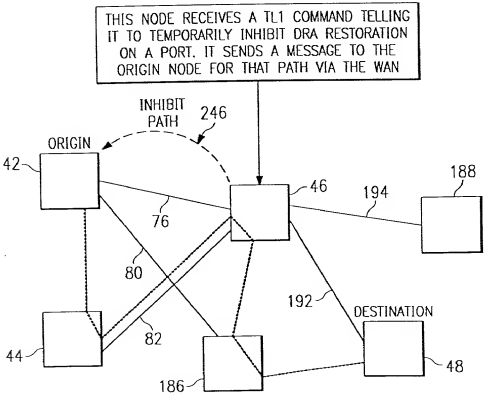

DRA IS NOT INHIBITED ALONG THIS PATH. IT IS RESTORED
ORIGIN
42
244
46
188
194
76
DRA IS INHIBITED ALONG THIS PATH. IT IS NOT RESTORED
80
240
192
DESTINATION
44
82
48
186

FIG. 44


THIS NODE RECEIVES A TL1 COMMAND TELLING IT TO TEMPORARILY INHIBIT DRA RESTORATION ON A PORT. IT SENDS A MESSAGE TO THE ORIGIN NODE FOR THAT PATH VIA THE WAN
INHIBIT PATH
246
ORIGIN
42
46
188
194
76
80
192
DESTINATION
44
82
48
186

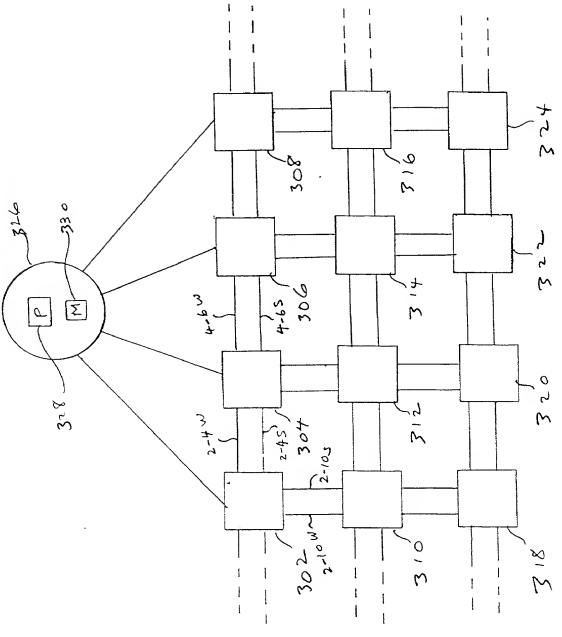

326
330
328
P
M
2-4W
2-4S
2-10W
302
304
308
4-6W
4-6S
306
310
312
314
316
318
320
322
324

Fig 45

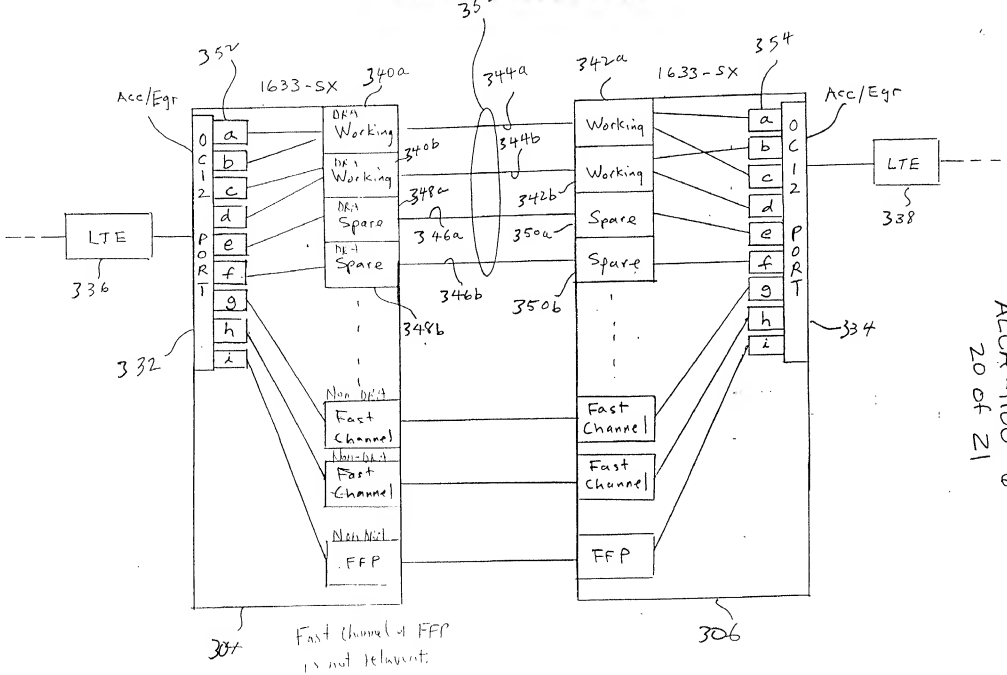

352
354
356
1633-SX
1633-SX
340a
342a
344a
344b
340b
342b
348a
346a
350a
346b
350b
348b
Acc/Egr
Acc/Egr
OC12 PORT
a
b
c
d
e
f
g
h
i
DFA Working
DFA Working
DFA Spare
DFA Spare
Working
Working
Spare
Spare
LTE
LTE
336
338
332
334
Non DFA Fast Channel
Non-DFA Fast Channel
Non-DFA FFP
Fast Channel
Fast Channel
FFP
304
306
Fast Channel & FFP is not relevant.

Fig 46

BEST AVAILABLE COPY

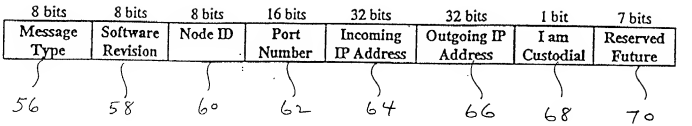


Fig 47

DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION

As the below-named inventor(s), I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention, design or discovery entitled METHOD AND MESSAGE THEREFOR OF MONITORING THE SPARE CAPACITY OF A DRA NETWORK, the specification of which

___X___ is attached hereto.

_____ was filed on _____, as Application Serial No. _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above; that I do not know and do not believe that said invention, design or discovery was ever known or used in the United States of America before my invention or discovery thereof, or patented or described in any printed publication in any country before my invention or discovery thereof, or more than one year prior to this application, or in public use or on sale in the United States of America more than one year prior to this application; that said invention, design or discovery has not been patented or made the subject of an inventor's certificate issued prior to the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns; and that I acknowledge the duty to disclose to the U.S. Patent and Trademark Office all information known to me

which is material to the patentability as defined in 37 C.F.R. § 1.56.

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application(s) in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose to the U.S. Patent and Trademark Office all information known to me to be material to patentability as defined in 37 C.F.R. § 1.56 which became available between the filing date of the prior application(s) and the national or PCT international filing date of this application:

Application Serial Number	Date Filed	Status
09/038,531	March 11, 1998	Pending

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

60/040,536	March 12,1997
(Application No.)	(Filing Date)

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

WILLIAM N. HULSEY III	Registration No. 33,402
STEPHEN E. REITER	Registration No. 31,192
GREGORY P. RAYMER	Registration No. 36,647
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BARRY N. YOUNG	Registration No. 27,774
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100 Congress Avenue, Suite 1440
Austin, Texas 78701

Full name of first inventor:	Paul T. Baniewicz
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Plano, Collin, Texas
Citizenship:	United States of America
Post Office Address:	1705 Falmouth Drive Plano, Texas 75025

==========

Full name of second inventor:	Ashley W. Brimmage
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Farmersville, Collin, Texas
Citizenship:	United States of America
Post Office Address:	1111 Willow Lane #3204 Farmersville, Texas 75442

Full name of third inventor:	Sridhar Alagar
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Richardson, Dallas, Texas
Citizenship:	India
Post Office Address:	2200 Waterview Parkway #1625 Richardson, Texas

Full name of fourth inventor:	Sig H. Badt, Sr.
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Richardson, Dallas, Texas
Citizenship:	United States of America
Post Office Address:	302 Trailridge Richardson, Texas 75081

Full name of fifth inventor:	Frederick R. Ellefson
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Allen, Collin, Texas
Citizenship:	United States of America
Post Office Address:	1001 Belvedere Court Allen, Texas 75013

Full name of sixth inventor:	Bryan J. McGlade
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Plano, Collin, Texas
Citizenship:	Australia
Post Office Address:	6516 Benchmark Drive Plano, Texas 75023

Full name of seventh inventor:	Lee Dennis Bengston
Inventor's signature:	_____
Date:	_____
Residence (City, County, State)	Murphy, _____, Texas
Citizenship:	United States of America
Post Office Address:	175 Moonlight Drive Murphy, Texas 75094